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Air Expendable Current Profiling During The OCEAN STORMS Experiment

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ABSTRACT

In the fall of 1987, 199 Air Expendable Current Profilers (AXCPs) were deployed from a NOAA P-3 aircraft as part of OCEAN STORMS, a study of air-sea interaction under strong storms in the northeast Pacific Ocean. The procedures used to prepare and launch the AXCPs are described, and the instrumentation and methods used to record, process, and display the received data in real time are detailed. The chronology of OCEAN STORMS and the AXCP drops is given, and a few examples of the profiles are provided. The modes of AXCP failure are reported, and recommendations for improving performance are made.

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EXECUTIVE SUMMARY

In the fall of 1987, the Applied Physics Laboratory deployed 199 air expendable current profilers (AXCPs) from a NOAA P-3 research aircraft as part of OCEAN STORMS, a large, international experiment to study the structure of strong, mid-latitude storms and their effect on the ocean. The AXCPs provided detailed profiles of the temperature and velocity in the upper 1500 m of the ocean before, during, and after the passage of several strong storms. These measurements, combined with those from moored and drifting oceanographic sensors, provided a three-dimensional, time-varying view of the ocean's response to such storms.

The system developed at APL for OCEAN STORMS recorded and processed signals simultaneously from three AXCPs in real time on board the P-3. The system was redundant in that no single failure could cause a loss of data. A multitasking HP9020 computer was the primary data-acquisition and processing system, with a four-channel PCM-VCR tape recorder as a backup. No data were lost despite several operator errors. A real-time display in the P-3 allowed modification of the sampling patterns in flight to optimize the use of a limited number of AXCPs.

Because the AXCPs failed at a higher rate than anticipated, a study was conducted during the experiment to improve their reliability. Most of the failures involved no reception of radio signals from the AXCP. These were correlated with the air speed of the P-3 at the time the probe was launched, with failures increasing above 210 knots true. There was no correlation with sea state, indicating the problem occurred at launch, not upon impact with the ocean. Video images of the AXCPs' behavior upon launching suggested that the air flow near the launch tube was highly turbulent, probably because of a large radar dome a few meters forward. It appears that this turbulence caused the parachute to deploy prematurely on some profilers, resulting in accelerations of 25 g or more transverse to the main axis of the AXCP and probably causing failure of some component in the RF transmitter.

Based on the AXCP's performance during OCEAN STORMS, a failure rate of less than 20% is expected if probes are launched at air speeds less than 210 knots and with the wind flaps down and facing forward. However, we recommend that mechanical tests of the AXCP be conducted to understand this problem more completely.

1. INTRODUCTION

The goal of the AXCP program conducted by APL during OCEAN STORMS was to measure the evolution of the velocity and temperature fields over several days during a period of strong storms. This report describes the AXCPs employed during that experiment, the procedures used to prepare and launch them, the instrumentation and procedures used to record, process, and display the received data in real time, and the AXCP failure modes. It also gives the times and locations of AXCP drops and provides a few examples of the profiles.

The standard AXCP (Figure 1) is an air-launched version of the XCP (Sanford et al., 1982) manufactured by Sippican. The entire unit is housed in a protective, A-size sonobuoy canister. Upon launch from an aircraft (Figure 2), a small wind flap deploys, pulling a parachute from the canister. The unit falls to the ocean surface at a rate of about 25 m s^{-1}. Upon impact, a seawater battery is activated, turning on the telemetry radio, opening a gas cartridge, and inflating the flotation bag. The pressure from the inflating bag pushes a steel plate out the end of the sonobuoy canister, allowing the surface unit to separate from the canister and rise to the surface. About 40 s later, an explosive squib fires and opens a door at the bottom of the surface unit; the probe is released to fall through the water column, where it measures temperature and relative velocity from a few meters below the surface to about 1600 m (Sanford et al., 1981). The probe falls at a rate of about 4.5 m s^{-1} and is connected to the surface unit by BT wire. About 6 minutes after impact, the wire breaks as the probe passes about 1500 m depth Useful scientific data end at this time, although the telemetry radio continues broadcasting. About 11 minutes after impact, the battery is shunted across a resistor, melting a hole in the flotation bag, scuttling the surface unit, and turning off the radio transmitter.

Two types of AXCPs were deployed in OCEAN STORMS: standard and "slowfall" units. The slowfall units were standard AXCPs extensively modified so that they would fall slowly though the upper 200 m to sample surface waves. The slowfall AXCPs are described by Osse et al. (1983) and their performance by Horgan et al. (1989). Operationally, the two types of probes were similar, and little distinction between them will be made here unless necessary.

From the Storm Transfer and Response Experiment (STREX) in 1980, we expected the coherence scales for velocity to be many tens of kilometers in the upper few hundred meters and much larger in the mixed layer. We expected these currents to be dominantly

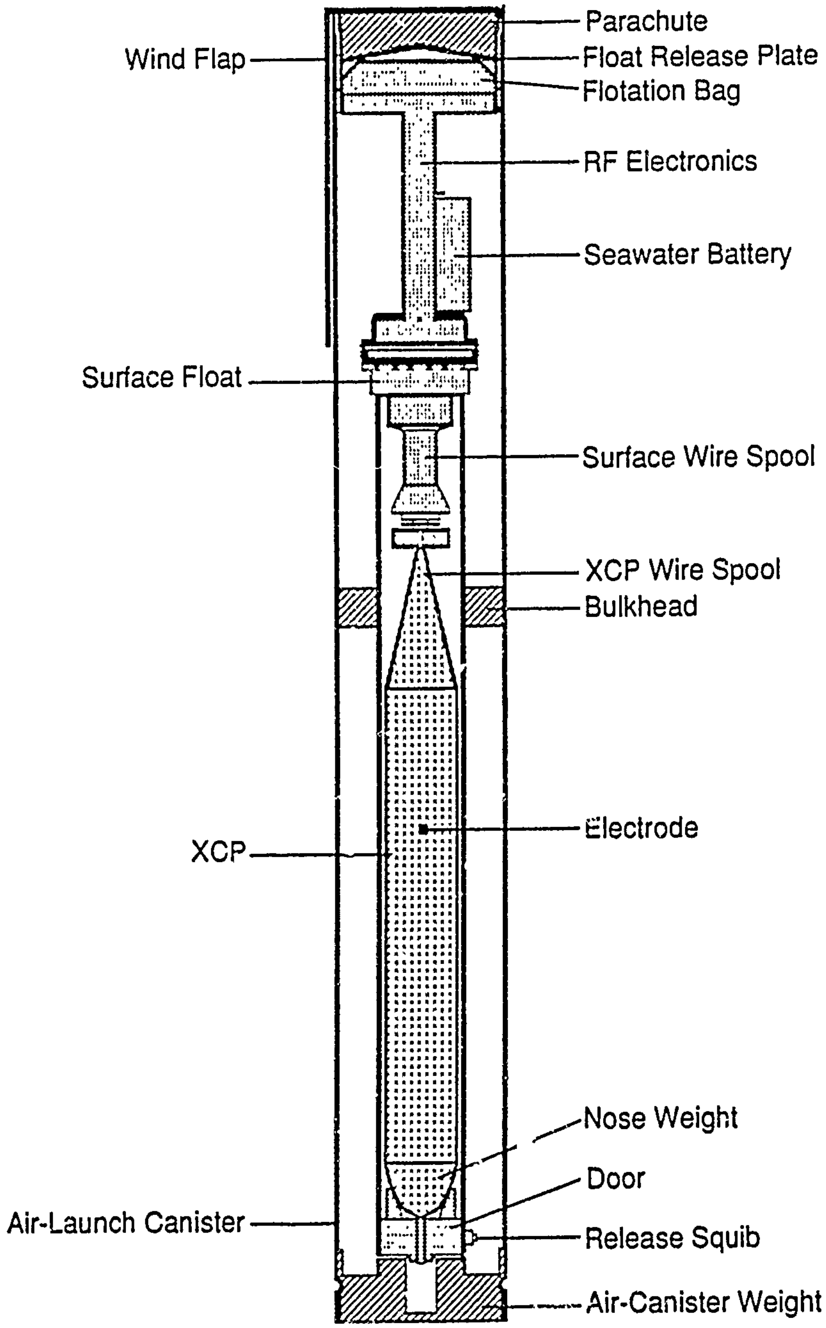


Figure 1. The AXCP. Shading indicates major parts of the probe: Air-launch canister, surface float, and XCP.

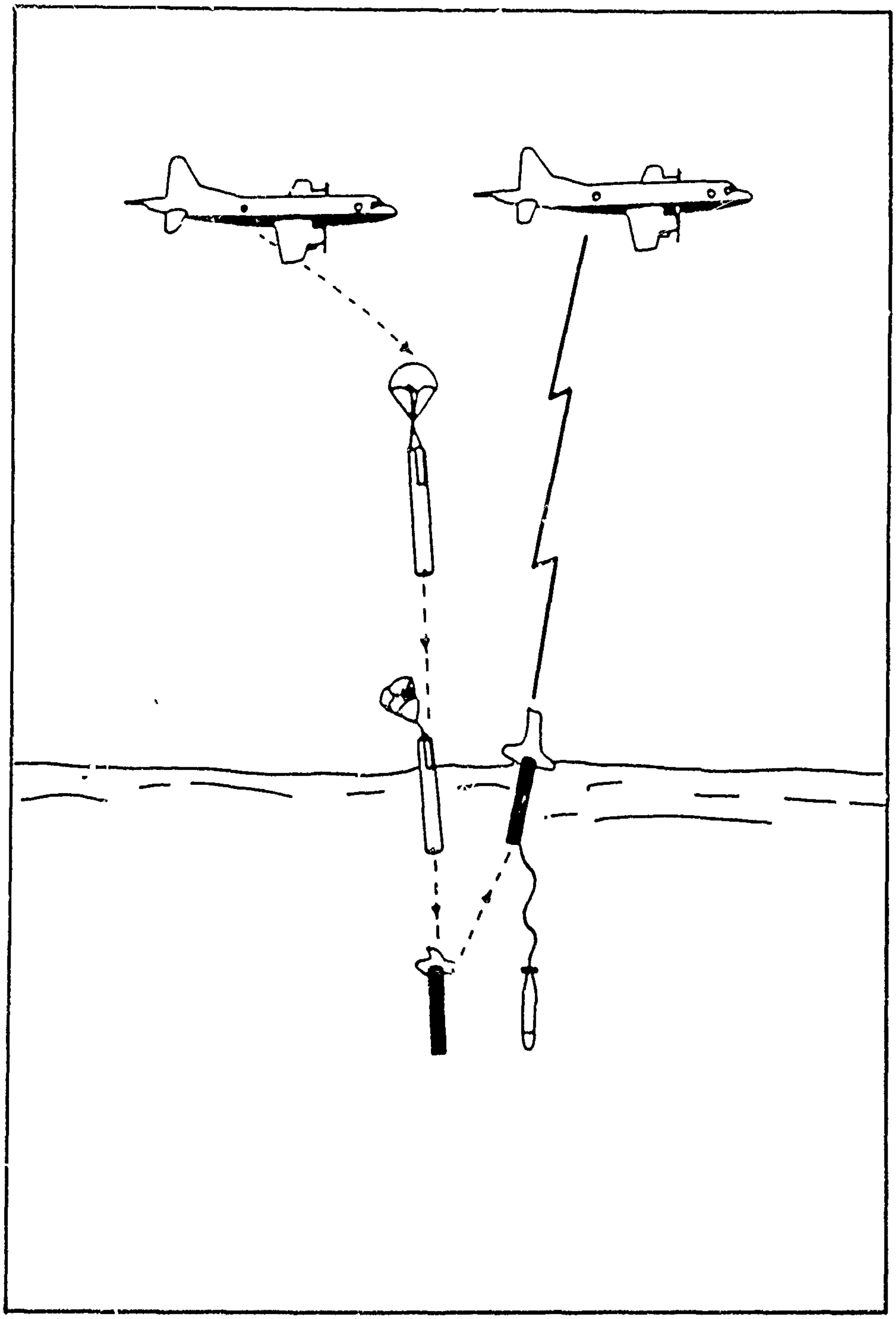


Figure 2. AXCP deployment sequence. Unit is launched from P-3; parachute deploys; air-canister separates and unit floats to surface; XCP is released and profiles oceanic velocity and temperature.

of near-inertial frequency, to be generated and modified by winds in excess of 40 knots, and to evolve, during periods of low winds, over a period of several days.

Because a single AXCP drop takes about 12 minutes from deployment to scuttling, and the minimum speed of the NOAA P-3 used to deploy the AXCPs is about 180 knots (5.5 km min^{-1}), the spacing of AXCPs would be about 60 km if only a single radio channel was used. Clearly, multiple channels were necessary. Practical constraints limited us to three channels, which allowed continuous operation with an AXCP spacing of about 20 km.

Our experience in previous experiments has demonstrated the great value of real-time data display. Real-time display not only allows a rapid diagnosis of evolving instrument problems, but also allows the sampling scheme to be modified depending on what is happening in the ocean. If, for example, the coherence scale of velocity had turned out to be 5 km instead of the 30–70 km anticipated, an immediate change would have been required in the sampling strategy. Accordingly, we needed a real-time display of the velocity and temperature profiles from each AXCP and an ability to replot recently taken profiles.

An aircraft-based study of storms places special requirements on the scientific equipment. Although the use of aircraft allows a large area to be surveyed rapidly, the sampling program itself also occurs rapidly, leaving little time to fix equipment or even diagnose problems. Strong storms may occur only a few times during the experimental period, and an equipment failure during those times could jeopardize the entire program. In addition, the sampling is limited by the finite number of AXCPs. If equipment or human failure results in data loss, the AXCP cannot be relaunched. For these reasons, the equipment must be very reliable and redundant, and the operational procedures must be well defined in advance. Our design goal was that no single failure would lead to the irretrievable loss of data or require the termination of the sampling program.

Rapid detection of problems with the equipment required continuously monitoring the performance of both the audio and RF signals received from the AXCPs. In addition, equipment and procedures were needed to quickly check out the performance of the entire system both on the ground and, as much as possible, during flights.

Section 2 of this report describes the AXCPs and the equipment used to record, process, and display the received data in real time. Section 3 describes the procedures used. Section 4 gives the chronology of OCEAN STORMS, and Section 5 describes equipment performance, including failure modes.

2. EQUIPMENT

2.1 Overview

A wiring diagram of the equipment installed on the NOAA P-3 is shown in Figure 3. The system was capable of receiving, recording, and processing three AXCP signals at once. Parallel digital and analog recording systems, each with its own antenna and radios, provided total redundancy for receiving and storing the data. The strength of the incoming RF signals was monitored by six meters, one for each radio. The audio signal from any one of the radios could be monitored using a headset and spectrum analyzer. Much of the equipment for both the analog and digital systems was housed in a single "patch panel" box, enclosed by the dotted line in Figure 3.

The digital system (forward antenna, Figure 3) used three Mk 10 XCP processing units, manufactured by Sippican and modified at APL, to decode and digitize the XCP signals and transmit them to an HP9020 computer. These raw data were time-stamped and stored on an HP9144 cartridge tape drive for post-flight reprocessing. The same data were processed in real time by the HP9020 and displayed on its graphics screen; a subset of the processed data was stored on the internal floppy disk drive of the HP9020. Data from the floppy disk could be rapidly replotted between periods of data acquisition.

The analog, or backup, system (aft antenna, Figure 3) used three radios within the "patch panel." The three audio signals were mixed with an 8 kHz "pilot" tone to allow compensation for tape wow and were recorded on three channels of a four-channel audio recorder (described below). Conversation on the P-3's intercom system was recorded on the fourth channel.

2.2 RF System

Several audio and radio frequencies were used in the AXCPs. The data were transmitted from the probe to the surface unit via BT wire using FM carriers of 500 Hz (temperature), 1200 Hz (electric field), and 2400 Hz (compass). The combined audio signal was transmitted from the surface unit to the aircraft using wideband FM (200 kHz bandwidth) on sonobuoy radio channels. Radio frequencies of 170.592 MHz (Channel 12), 172.083 MHz (Channel 14), and 173.584 MHz (Channel 16) were used during OCEAN STORMS.

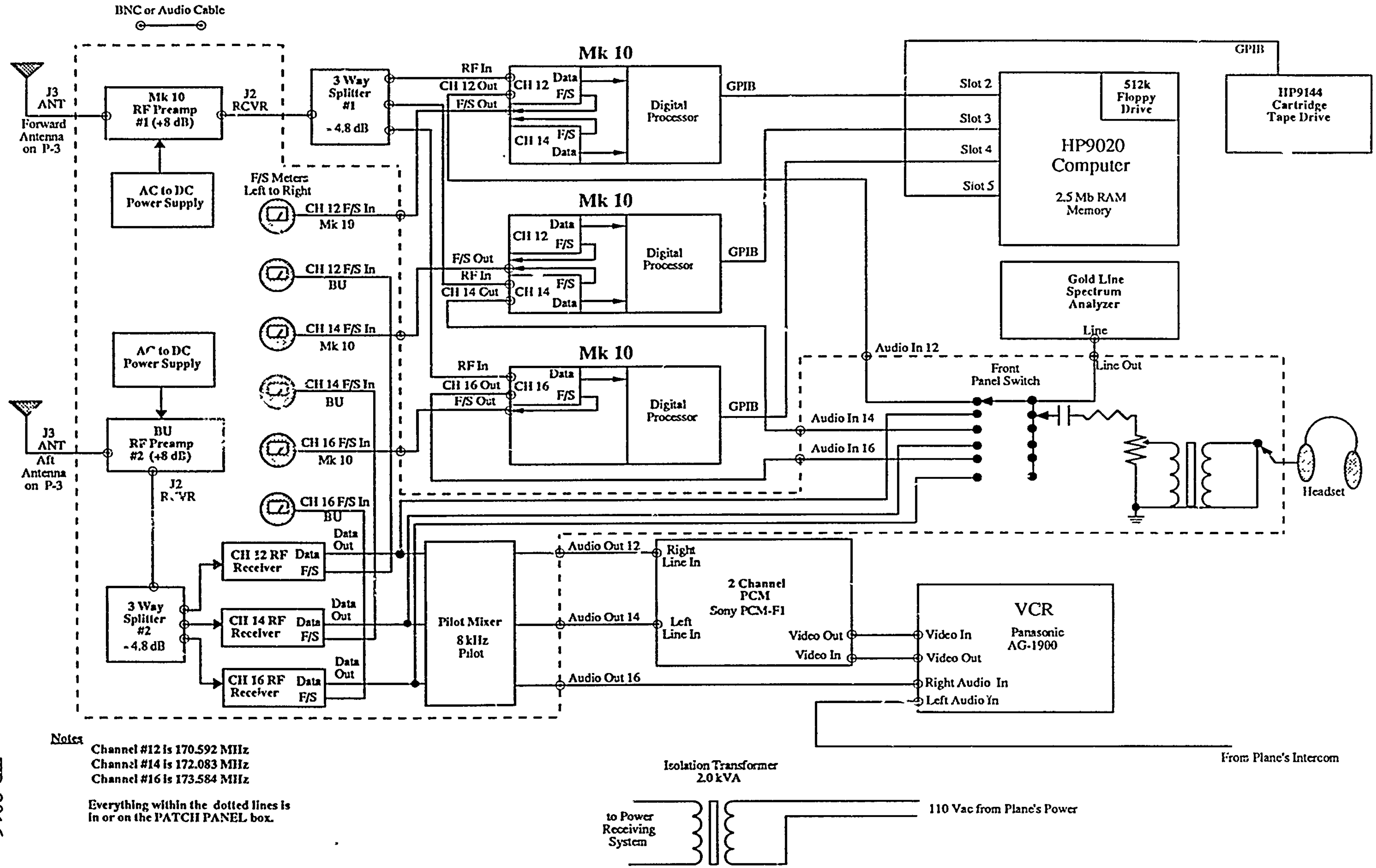


Figure 3. OCEAN STORMS AXCP aircraft receiving system.

RF signals from the AXCP were received using two Dayton-Grange (part #16355) VHS 143–174 MHz, vertically polarized, omnidirectional, dipole antennas mounted on the tail of the P-3. The signal from each antenna was boosted 8 dB with a broadband RF preamplifier (Joslin Defense Systems, Communitronics model 50548-03-20) and then distributed to three RF receivers (Joslin Defense Systems, model 51011-02-01), one for each channel. For the digital system, the receivers were mounted in and powered by the Mk 10s as supplied by Sippican, although the three-way splitter supplied by Sippican and mounted inside the Mk 10 was removed. For the analog system, the receivers were mounted in the patch panel and powered from an independent power supply. The output of the AGC from each receiver was used to drive a small ammeter on the patch panel and thus provide a qualitative measure of the RF signal strength. Before being recorded, the AGC output was also converted to a frequency and mixed with the audio XCP data on channel 14 of the analog data system to provide a more quantitative measure of the signal. This system was calibrated by putting a known level of RF energy into the receiver and measuring the resulting frequency. The calibration data were as follows:

Received RF Power (dBm)	Voltage	Frequency (kHz)
<–130	0.447	10.502
–120	0.448	10.518
–110	0.455	10.670
–100	0.489	11.447
–90	0.598	13.952
–87	0.668	15.570
–85	0.733	17.077
–80	0.800	18.596

2.3 Analog System Hardware

The analog XCP system provided a simple backup for the digital system. Other users may wish to avoid the complexity and size of a digital system and use a purely analog system as was done by Sanford et al. (1987).

The analog data were recorded using a Panasonic AG-1900 industrial VCR and a Sony PCM F1 digital recording unit. The PCM stored two channels of audio data in digital format on the video channels of the VCR. Two additional channels were provided by the "hi-fi" feature of the VCR. The combination could record four channels of XCP data with little or no measurable degradation of the signal. The system appeared to be little affected by the vibration of the aircraft. In our configuration, AXCP channels 12 and 14 were recorded on the right and left channels of the PCM, respectively. AXCP channel 16 and the P-3 intercom were recorded on the right and left "hi-fi" channels of the VCR, respectively. The record level was set below 10 dB for the VCR hi-fi and below 20 dB for the PCM to avoid possible distortion caused by pre-emphasis circuits. The low output levels of both devices required amplification before playback into a Mk 10.

The analog quality of the AXCP signals was monitored using headphones and an inexpensive, low-resolution spectrum analyzer (Gold Line RTA model 30, designed to balance the sound for live music performances) to provide an analog indication of AXCP performance. As a general rule, if we could hear the audio signal from an AXCP, it was strong enough to process and produce good data. The key signals from the AXCP when using this system are shown in Table I.

Table I. Audio signals received from the AXCP during OCEAN STORMS and their meanings.

Time	Event	Signal	Meaning
0	AXCP reaches surface	RF quieting	AXCP floating, RF transmitter working
		No quieting	RF-type failure
40 s	Probe released	Slight pop	Probe release squib has fired
	Probe transmitting data	Warbling sound	Wire is OK, probe working
		Regular warble	Probe falling and spinning
		Irregular warble	Probe stuck in surface unit - AF failure
		No sound	Dead probe or wire broken - AF failure
		Spectral line near 500 Hz	Temperature data being transmitted
		Spectral line near 1200 Hz	Electric field data being transmitted
		Spectral line near 2400 Hz	Compass coil data being transmitted
6.5 min.	Wire breaks	Audio signal stops	End of AXCP data
11.5 min	AXCP scuttled	RF quieting stops	Radio channel clear
Any	Other	Dropouts in audio data	Radio propagation problems
			Probe getting too far away
			Aircraft too low

2.4 Digital System—Using the Sippican Mk 10

We found the Sippican Mk 10 XCP processors to be adequate, if not ideal, for digitizing XCP data, provided that several modifications are made to their hardware and switch settings.

The Mk 10 "decides" whether XCP data are "good" or "bad" depending on the setting of four DIP switches on board A2. Four criteria are available: the existence of temperature (T), compass coil (CC), and electric field (EF) audio carriers and the modulation of the compass carrier by the rotation of the XCP at frequencies in the 10–20 Hz band (PF). Far better choices on data quality can be made in software than in hardware, so we disabled all the criteria except item CC (i.e., switches 2, 3, and 5 were open; 4 was closed) so the maximum amount of data was sent to the computer. Disabling all the criteria doesn't work.

The Mk 10 decides whether it is listening to "real time" or "playback" data by looking for energy at the frequency of the 8-kHz pilot tone put on recorded data to compensate for tape wow. Because radio noise can insert a signal at this frequency, we disabled this feature by grounding pin 12 of opamp U8 on board A2. Closing DIP switch 8 on board A2 thus set the Mk 10 into a "real time" mode. This switch should be closed during real-time operations.

The Mk 10 digital processor can be confused by long periods of radio noise between drops. When this happens, the digital system locks up and must be reset, usually by turning the power off and on. To avoid repeated power-ups, we installed a reset switch on the front panel of our Mk 10s. The switch momentarily set pin 9 of the Mk 10's 8031 microprocessor (board A1) to +5 V. When the switch was depressed, the microprocessor, and thus the Mk 10, was reset as if the power had been turned off and on. We did not protect the switch mechanically. As a result, it could be, and was, pushed while data were being acquired. The switch has since been protected. Generally, we used the reset switch before starting up the Mk 10 if it had been turned on and left in the startup state for any length of time.

2.4.1 *Computer Requirements*

The computer requirements for acquiring and displaying AXCP data are as follows:

HPIB Interface — A separate IEEE-488 (HPIB) interface is required for each Mk 10, since the bus address is always 22. The number of Mk 10s that can be used with a given system may often be limited by the number of available I/O slots in the machine.

I/O rate — The Mk 10 generates a packet of 17 bytes once per revolution of the XCP, typically every 60–70 ms; extra packets due to radio noise can decrease the average interval to perhaps 40 ms, with a few cycles separated by as little as 5 ms. Thus the total data rate is generally less than 425 bytes/s.

Servicing Interval — The Mk 10 has an internal buffer which can hold only 128 bytes and thus needs to be emptied about every 300 ms. This requirement is often hard to meet with a multiuser, nonreal-time operating system.

Storage for Raw Data — Each XCP drop lasts about 350 s and thus contains about 145 kbytes of raw Mk 10 data. For AXCP work, however, we ran the Mk 10 continuously and saved all the data. This produces about 1.5 Mbytes of raw data per hour for each channel. Three hours of data gathering with three AXCP channels thus produces about 14 Mbytes of data. This is too much to store on floppy disks, but is easily handled by hard disks or cartridge tape drives.

Storage for Processed Data — Typically, processed data are computed on an approximately 3 m grid, with each grid point consisting of about 10 scientific and engineering variables. A processed profile thus consists of about 5000 words of data.

Processing Power — Processing an XCP profile at full resolution requires roughly 3 million floating point operations. If this is to be done in real time, a processing rate of about 10^4 floating point operations per second (10 kflops) is required for each channel processed. Processing the data at less resolution can reduce this requirement substantially; we have, for example, run a nearly real-time XCP acquisition program on an HP9845 with a speed of about 3 kflops.

Data Display — We displayed eight variables for processed XCP data: temperature, velocity, velocity error, and four diagnostic variables. With multiple AXCP profiles, this can rapidly fill up a graphics display screen. We found a color monitor to be nearly essential. A large color monitor with several screens or windows would be very helpful.

Power — We experienced no problems with the electric power generated on the NOAA P-3 during flight. On the ground, however, power was sometimes supplied by portable generators (of unknown quality) provided by the airport. We suspect that power from one such generator caused a computer failure. We therefore installed a high-quality isolation transformer to protect any electronics installed on the aircraft.

Environmental Requirements — An aircraft is a high-vibration environment. We mechanically isolated our system, using Aeroflex stainless steel shock mounts, although most users of the P-3 have not. Some hard disks are known to have failed because of the pressure shock wave induced during an AXCP launch. We experienced no such problems, although we did not access the HP9020 hard disk in flight. Nine-track tape drives, cartridge tape drives, and floppy disk drives were used during our flights without any apparent problems. Audio cassette tape players installed without shock mounts have experienced problems with vibrationally induced noise. This may also happen with some digital equipment.

Aircraft Requirements — All equipment mounted in the NOAA P-3 was required to remain fixed in place under a combined acceleration of 2.5 g vertical and 10 g forward for crash safety. In addition, the weight of the equipment at our assigned station could not exceed 500 lb.

2.4.2 *Equipment used during OCEAN STORMS*

An HP9020 computer workstation running a multitasking, real-time BASIC operating system was used to digitize, store, process, and display the data. It did an excellent job, although it nearly exceeded the P-3 weight limits for a single station. Equipment installed by APL in the NOAA P-3 was mounted in a specially designed rack as shown in Figure 4. That equipment consisted of the following:

HP9020

- 1 CPU
- 2.5 Mbytes of RAM
- 3 Gpib cards (slow speed) for Mk 10s
- 1 Gpib card (fast speed) for 9144 tape drive
- Internal 10 Mbyte hard disk (used for program storage only)
- Internal 264 kbyte 5.25-in. floppy disk drive (used for processed AXCP data)
- Standard color CRT, 512 × 390 pixels
- Internal thermal printer with graphics dump

OAO standard display consisting of two TV monitors and a selection switch.

9144 cartridge tape drive with 16-Mbyte cartridge (for raw AXCP data)

3 Mk 10 digital XCP processors modified as described previously

An electronics box containing power supplies, radios, RF display, and pilot generator and mixer ("patch panel" in Figure 3).

In addition, a 2000 V-A isolation transformer was mounted near the rack to filter power from the P-3.

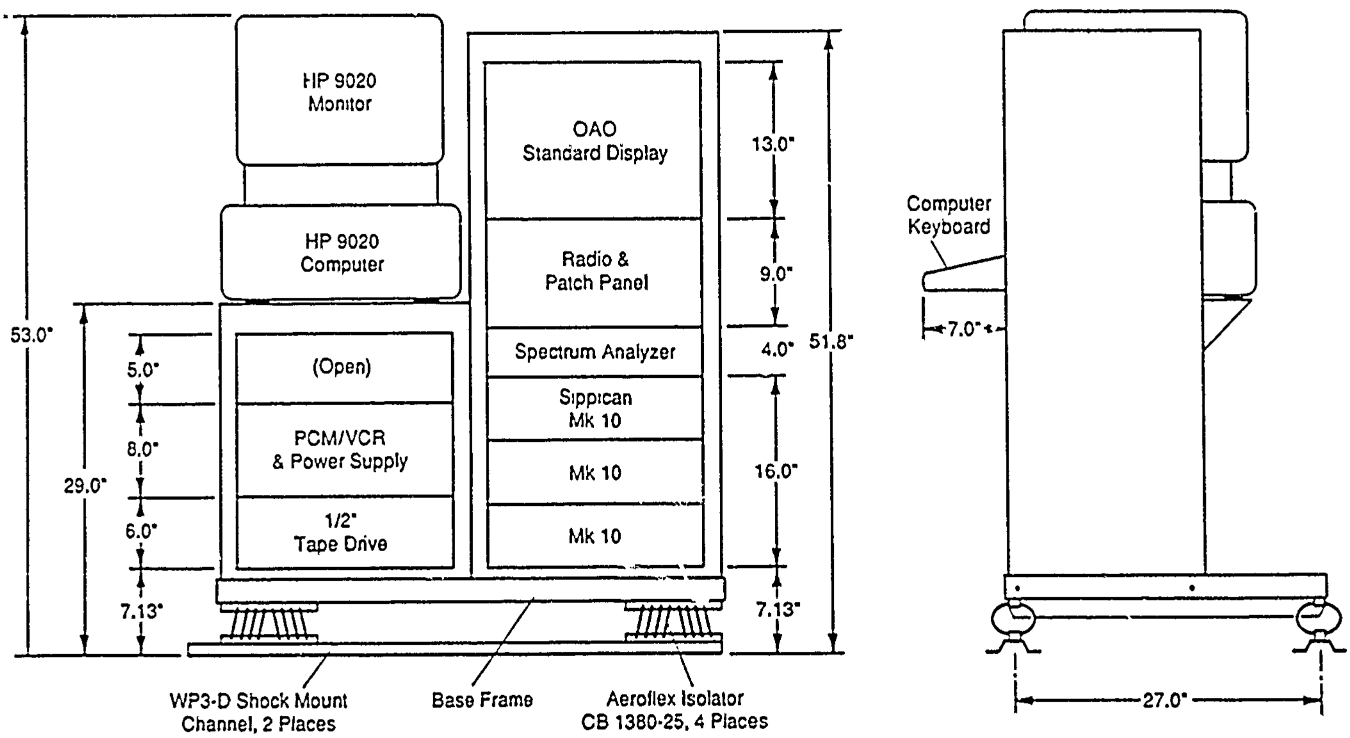


Figure 4. Configuration of AXCP equipment rack used for OCEAN STORMS.

2.5 Software

2.5.1 Design Goals

At the start of this project, only the single-channel, real-time AXCP software from Sippican and a similar program written at APL were available. Neither could handle the number of channels or the volume of data anticipated for OCEAN STORMS. We therefore chose to write new software to accomplish the following tasks:

(1) Read three channels of data from Mk 10s, store these data on a cartridge tape drive, and allow this process to be monitored.

(2) Scan the data on each channel, automatically determine whether AXCP data were being received, and, if so, process and display these data in real time and store them.

(3) Replot AXCP profiles in-flight for preliminary scientific analysis so the sampling strategy could be modified.

(4) Provide hard copy output of program states and errors, AXCP drop beginnings and endings, and operator comments.

Several desirable features such as plotting the aircraft's track, integrating the P-3's navigational and time information into the AXCP data stream, and remotely displaying AXCP data were not attempted owing to a lack of I/O slots in the HP9020.

Figure 5 shows the data flow for the AXCP software. The HP9020 operating system allows the creation of separate partitions, each of which operates as a virtual machine. A separate "data" partition was used to communicate with each Mk 10 and process and display the data received from it. A fourth, "master," partition collected the data from all three data partitions, wrote them to the cartridge tape and floppy disk, and signaled the data partitions to start and stop data acquisition.

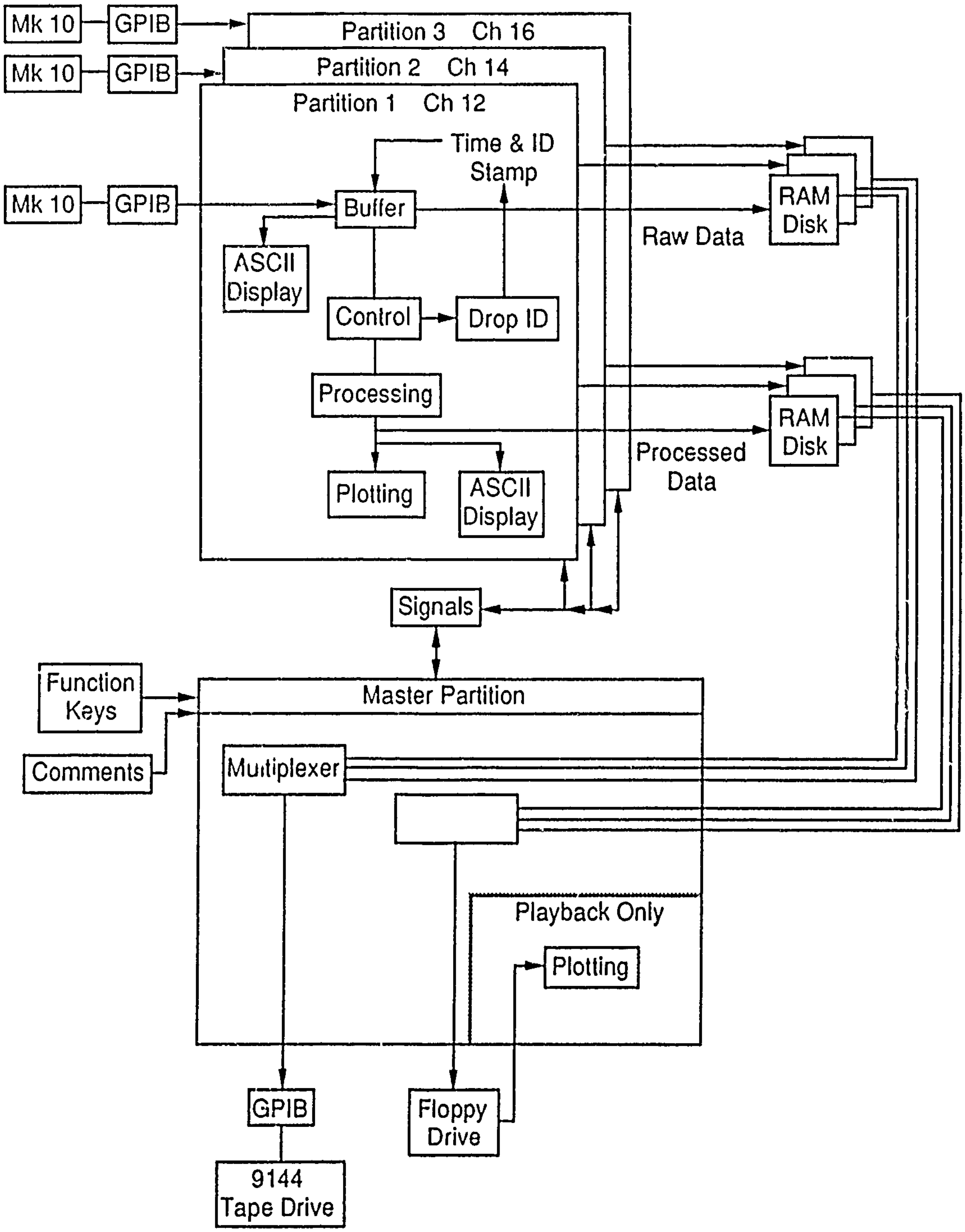


Figure 5. Data flow in AXCP real-time software.

2.5.2 *Mk 10 Protocols*

A key part of the data-acquisition system is proper use of the Mk 10s, which can be disabled by radio noise if the correct protocols are not used. The three Mk 10 states are as follows:

State	Description	Recommended Use
Power-on	Mk 10 vulnerable to radio noise	Get out of this state after power-up or reset
Wait	Mk 10 waits	Idle
Run	Mk 10 sends data	Data gathering

These states can be changed by signals from the HPIB. Table II shows the signals sent on the HPIB to change the Mk 10's state and the Mk 10's response. Detailed information on Mk 10 operation can be found in the Sippican Mk 10 manual.

Table II. Mk 10 commands.

Action	Computer sends	Mk 10 Replies	Meaning
Power-on to wait	U (55H)	VCbbS (56H, 43H, two id bytes, 53H) VCbbS (56H, 43H, two id bytes, 55H)	OK Not OK
Wait to run	L110(4CH,01H,01H,00H)	R (52H)	Start data acquisition
Run to wait	X (58H)	None	Suspend data acquisition
Wait to power-on	XXXX (58H 4 times)	None	

2.5.3 *AXCP Data Processing (APL)*

In the program written by APL, data are received from the Mk 10s in groups of 30 scans of 17 bytes each using asynchronous reads controlled by the 9C .0's I/O processor. A 34-byte tag containing time and ID information is then added to the data, and they are stored in a buffer. When 64 such reads have been completed, the data in the buffer are written to a RAM disk, and a signal flag is set. The master partition recognizes the signal, reads the RAM file, and writes it to the tape drive. Data from each of the partitions are thus interspersed on the tape drive. The tag on each group of 30 scans, however, unambiguously identifies its origin.

Simultaneously, but at lower priority, the data from the Mk 10 are read from the buffer and processed. A significant innovation in this software is a new procedure that discriminates between noise and XCP data and thus allows the start and finish of a drop to be determined automatically. The processing program can therefore operate with minimal attention by the operator. As discussed previously, we set up the Mk 10s to give "good" data packets as often as possible, even, for example, when only radio noise was being received. The software discriminates AXCP data from noise by examining the rotation rate of the AXCP. The rotation rate is always between 10 and 20 Hz for a regular AXCP and between 0 and 20 Hz for a slowfall AXCP. The rotation rates produced by noise, on the other hand, are usually greater than 20 Hz. The beginning of a drop is therefore found by looking for a large number of consecutive data packets (here, 50) for which the rotation period is within the "nonnoise" range. Near the end of an AXCP drop, good data are often interspersed with bursts of radio noise. A very conservative criterion is therefore used to detect the end of a drop. If the rotation rate is within the allowed range for AXCPs, a quality index is set to 1; if not, it is set to zero. The end of a drop is defined when the quality index, recursively averaged with a decay time of 100 data scans, is less than 0.3. This algorithm for detecting drop beginnings and endings functioned accurately during OCEAN STORMS. The start and stop of all drops were detected correctly, and only a few false starts occurred.

The data processing itself was very similar to that of Sanford et al. (1982). Velocity, temperature, and the quality control variables were computed from data averaged over 22 probe rotations with a new value output every 11 rotations. These data were plotted on the 9020 CRT. At the end of each drop, the scientific variables were written to a RAM file which was then transferred to a floppy disk file by the master partition.

The acquisition program can be paused and restarted as often as desired. When the program is paused, no data are written to the tape drive. During this time, the AXCP profiles stored on the floppy drive can be displayed by a plotting routine.

2.6 Setup of Equipment in NOAA P-3

Figure 6 shows the layout of the P-3 for OCEAN STORMS. Key locations for the AXCP work are labeled.

Launch Tube — The tube through which the AXCPs exited the aircraft was located in an open area in the tail half of the cabin.

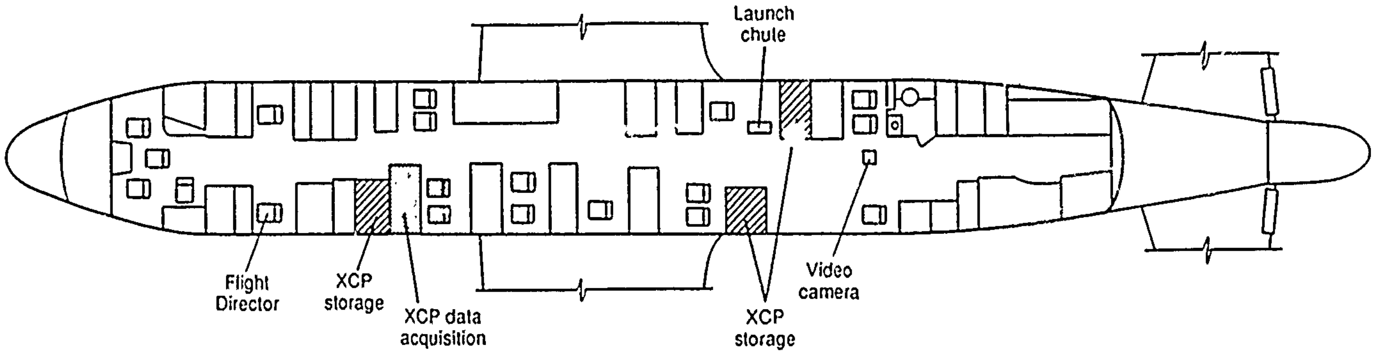


Figure 6. Location of AXCP equipment in NOAA P 3 during OCEAN STORMS.

AXCP Station — The AXCP receiving equipment was located forward, near the propeller plane and about 8 m from the launch tube. All the equipment was stored in a shock-mounted rack secured to rails in the aircraft floor. Two seats were located in front of the rack; the outboard seat was in front of the 9020 computer screen, and the inboard was in front of the patch panel, spectrum analyzer, and P-3 scientific display tube. All the displays could be easily seen from either station.

Probe Storage on P-3 — AXCPs were stored both next to the launch tube and forward in the aircraft next to the AXCP station. Forward stowage was needed to keep the aircraft's center of gravity as far forward as possible. This required that the probes be moved from the forward storage to near the launch tube during the flight. The forward probes were stored upright in a wooden rack with links of chain screwed into it. Elastic (bungee) cords were then hooked into the chain links to hold the probes in place. The aft probes were stored on their sides and stacked like firewood. The pile was then held to the floor with elastic cords.

2.7 Support Equipment

A variety of support equipment was used during the experiment to maintain a reliable system and allow the AXCP work to proceed smoothly.

Mobile Field Station — A portable building, designed for use at construction sites, was leased and set up next to the aircraft at Boeing Field, Seattle. It was used to store AXCPs, test equipment, spare parts, and tools for easy maintenance and testing of the

AXCP system. A cellular phone was kept at the field station so that engineers could easily call APL. This proved invaluable many times.

AXCP Test Box — We have found that the single most valuable piece of equipment for XCP work from any platform is a test box that simulates an XCP drop. This is constructed using one or more radio transmitters taken from XCPs, is powered by batteries, and uses a small tape recorder to generate the XCP audio signal. Figure 7 shows how to wire the radio transmitter board once it has been removed from the XCP. One or more such transmitters are mounted inside a metal box, with an external antenna. An important part of this system is a foolproof "off" switch, or several redundant switches, so that the transmitter does not activate inadvertently during data acquisition and overpower the real AXCP signals. During OCEAN STORMS, we used a test box with three radio channels—12, 14, and 16—so that the transmissions of up to three AXCPs could be simulated. This test box was used to debug the AXCP receiving system during development, to check the operation of the system routinely before each flight, and to test the operation of the radio receivers during a flight.

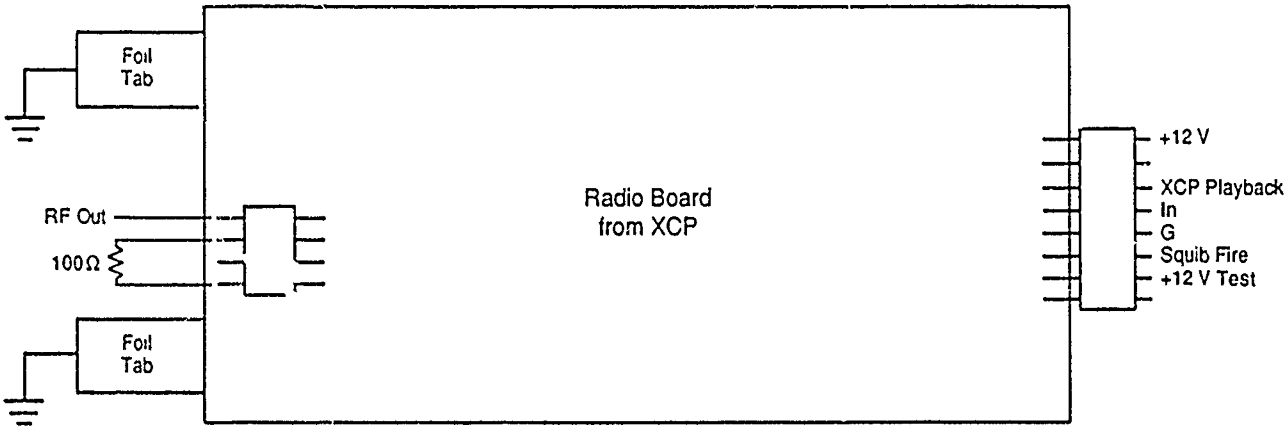


Figure 7. Pinout for RF transmitter board on XCP.

3. PROCEDURES

Probe Testing — All AXCPs were tested before use. In this experiment, only one failed the test. In other experiments, up to 3% have failed. Details of testing procedures are included in the appendix.

Probe Labeling — Typically during OCEAN STORMS, several AXCPs were transmitting at once. It was thus important that a probe not be launched while another of the same frequency was still transmitting. As much as possible therefore, the order of probe launch was set ahead of time, and the probes were labeled and stored in the expected launch order. A list of probe launch order, serial numbers, and RF channels was distributed to cognizant personnel on the airplane before the operations started. Some additional probes, designated "fillers," were often loaded for use if one or more of the planned probes failed. These were labeled separately and listed on a separate log sheet.

Pre-Flight Checkout — The AXCP system was tested before each flight by simulating drops on each channel with the XCP test box.

Probe Loading — Probes were loaded onto the P-3 immediately before a flight. Some care was necessary in loading so that the probes would be accessed in the designated drop order.

In-Flight Checkout — During the flight from Seattle to the launch site, the system was monitored to verify that the radios and computer were still working. Several strong RF sources in Puget Sound were used to verify that the radios were working. Shortly before the start of AXCP work, we typically launched three AXBTs, one for each radio channel, to verify that the system could pick up weak radio sources on the ocean surface.

Communications and Navigation — Communication on board the P-3 was accomplished mostly through the plane's intercom system. Because intercom traffic was recorded on the PCM/VCR system, a record of almost all communications was preserved. Navigational information, as well as speed, altitude, and much meteorological data, was displayed on the standard display available at numerous points in the plane, including the AXCP station.

Flight Planning — Meteorological briefings were held daily at 1400 hours at the OCEAN STORMS meteorological center established at the National Weather Service offices in Seattle. In addition, information from OCEAN STORMS drift buoys was available at APL daily. Based on these data, a flight was tentatively planned for the next day. If a flight was called, additional meteorological briefings were scheduled. Flight planning was governed by P-3 operating rules designed to allow the crew and plane proper rest and maintenance. If no flight was planned, none could be undertaken, as the aircraft and crew would not be prepared. A flight could be canceled up to 2 hours before takeoff.

Personnel -- AXCP drops on the NOAA P-3 involved the following people:

> *Scientist* (APL) — The scientist was responsible for the program. He sat at the inboard seat of the AXCP station, where he could see both the computer screen and patch-panel indicators and quickly get back to the launch station.
>
> *AXCP Data Technician* (APL) — The data technician sat at the outboard seat of the AXCP station in front of the computer screen. He was responsible for setting up and running the data acquisition system.
>
> *AXCP Launch Technician* (APL) — The launch technician worked near the launch tube. He was responsible for preparing the AXCPs for launching in the correct order, giving the AXCPs to the AXCP launcher, and logging the times of the drops.
>
> *Flight Director* (P-3) -- The flight director was the interface between the scientific party and the flight crew on the NOAA P-3. During AXCP operations, he was responsible for directing the time and place of each drop, following the instructions of the scientist.
>
> *AXCP Launcher* (P-3) — This person pushed the AXCP down the drop tube when instructed to do so by the flight director.

Drop Planning — Because of air traffic controls, reservations to operate the P-3 in a given area usually had to be made several hours in advance. Fine tuning could be made more rapidly, but was not always permitted. Accordingly, the location and timing of the AXCP drops were usually planned before a given flight, although the details were often worked out during the 2 hour ferry to the operating area. This plan was given to the flight director, who was then responsible for directing the aircraft and scientific party.

Drop Execution — Typically, data acquisition was begun a few minutes before the first AXCP drop. The launch technician would prepare the next AXCP for launching by following the instructions on the "AXCP Launch Log" (included in the appendix). The protective tape removed from the AXCP would be attached to the log to document that the tape had been removed. The flight director would give a 1-minute warning of the drop and then instruct the AXCP launcher to drop the probe. The launcher would call "mark" at the time of the drop. At this "mark," the data technician would insert a comment on the 9020 computer as to the number and RF channel of the drop. The time of this comment would be automatically logged by the computer for later reference. In addition, the launch technician would manually log the time, and the scientist would write down the location of the drop and plot it on a clipboard chart.

Typically, drops were made at an altitude of 5000 ft. From this height, an AXCP would reach the surface in approximately 1 minute. The data technician would mentally note the expected time to the surface and monitor the RF level meters, spectrum analyzer, and headphones to detect the radio quieting when the AXCP radio transmitter turned on. If this occurred, he would make a note to this effect on the computer. Approximately 40 s later, the AXCP probe was supposed to deploy. The data technician would also monitor this event and note if it occurred. If either event did not occur, the scientist would decide whether to drop a fill-in probe or to accept the loss. If a fill-in was desired, the scientist would notify the flight director, and a drop would be made as soon as possible.

In-Flight Data Analysis — The real-time data display allowed the scientist to monitor AXCPs currently in the water or recently finished. Often, however, the flights were designed with breaks between AXCP deployments to allow a slightly more thorough analysis. This also allowed the aircraft to fly, for example, to the other side of the operations area so that a line of AXCPs could be dropped from a different direction. During these breaks, data acquisition was shut down, and AXCP data taken during the last leg of the flight were plotted for examination by the scientist.

4. OCEAN STORMS CHRONOLOGY

Activities during OCEAN STORMS, including AXCP operations, are listed briefly in Table III and detailed in the following paragraphs.

The nine-element moored array deployed on R/V *Melville* on 17–24 August 1987 included a subsurface mooring, three profiling current meters, and five surface moorings, four with surface meteorology. An array of eight bottom pressure and electric field gauges was also deployed.

During the CTD survey of the experimental area from 21 September to 16 October with CSS *Parizeau*, 38 Lagrangian drifters, meteorology/thermistor chain drifters, and two French meteorology/thermistor chain buoys were deployed. About half of these were in the water during the passage of a strong cyclone over the array on 4 October. Surface currents of up to 1 m s^{-1} were measured, followed by strong inertial currents which persisted for about 10 days.

The OCEAN STORMS meteorological office was in operation from 19 October to 9 December and was supported jointly by the U.S. and Canadian weather services. It provided forecasts for the experiment as well as digitized weather analyses every 6 hours.

The NOAA P-3 research aircraft arrived at Boeing Field in Seattle on 21 October. The AXCP equipment was installed and tested on 21 and 22 October. A flight was made on 23 October to test the AXCP receiving and processing equipment. AXBT and AXCP drops were made in the closest deep water, off the southern Washington coast. Four AXBTs were dropped, and two worked. Three AXCPs, two regular and one slowfall, were dropped in rapid succession, and all three worked. The data-acquisition system performed as expected.

A "pre-frontal" flight was made on 25 October in anticipation of a strong storm expected the next day. The AXCP drop pattern was centered on the moored array. Because of concern that the AXCPs might foul or otherwise damage the moorings, all AXCP drops were made at least 5 miles away. This necessitated a flight path with several jogs (Figure 8). The flight pattern was executed easily, clearly demonstrating the ability of the P-3 to make precisely navigated AXCP drops. The final, backtracking leg demonstrated the ability of the aircraft to make additional drops to fill in gaps due to probe failures.

Table III. Summary of events during OCEAN STORMS, 1987.

17 Aug–24 Aug	Moored array deployed from R/V *Melville.*
21 Sep–16 Oct	CTD survey and buoy array deployed form CSS *Parizeau.*
19 Oct–9 Dec	OCEAN STORMS weather office in operation.
21 Oct	NOAA P-3 arrives at Boeing Field, Seattle.
21 Oct–21 Nov	Buoy deployment and turbulence measurements from CSS *Parizeau.*
23 Oct	AXCP test flight with P-3.
25 Oct	Pre-frontal AXCP flight.
25 Oct–13 Nov	NASA C-130 flights.
5 Nov	P-3 operations suspended.
19 Nov	P-3 operations resume.
21/22 Nov	Pre-storm AXCP flight
24 Nov–9 Dec	CTD survey from CSS *Parizeau.*
1 Dec	Storm AXCP flight.
2 Dec	Post-storm AXCP flight.
4 Dec	Storm AXCP flight.
5/6 Dec	Post-storm AXCP flight.
6 Dec–9 Dec	Equipment unloaded from P-3.

During the outbound flight, the RF meters behaved erratically because of high vibration levels due to stacking the AXCPs against the back of the rack and "short-circuiting" the shock mounting. A better method of storing the AXCPs was designed before the next flight.

In all, 31 regular AXCPs and 1 slowfall AXCP were dropped on 25 October. The success rate was much less than we had hoped, approximately 62%. Subsequent discussions with Sippican resulted in a launch procedure (see p. 55) that substantially increased the success rate in later flights. AXCP failures are analyzed in Section 5.

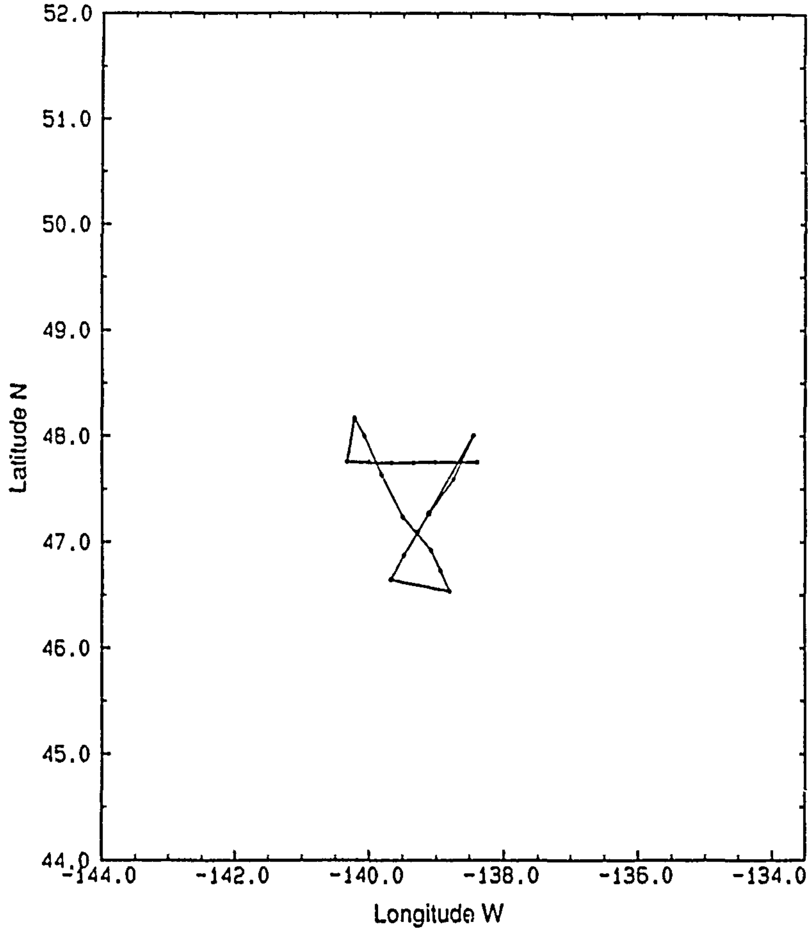


Figure 8. Flight track for 25 October 1987. Dots indicate successful AXCP drops.

Data from this flight showed strong currents, probably of inertial frequency, in the upper ocean but below the mixed layer. An example of the data is shown in Figure 9. These currents most likely were produced by the strong storm on 4 October. Data from the drifting buoys showed that inertial currents clearly produced by this storm disappeared from the mixed layer about 10 days before this flight.

The storm on the next day was not of sufficient intensity to warrant additional flights.

Few storms were observed during the next 2 weeks, and the long-range weather forecasts did not indicate any were likely soon. The NOAA P-3 crew was therefore sent home for 2 weeks in the hope that storms would occur in late November or early December.

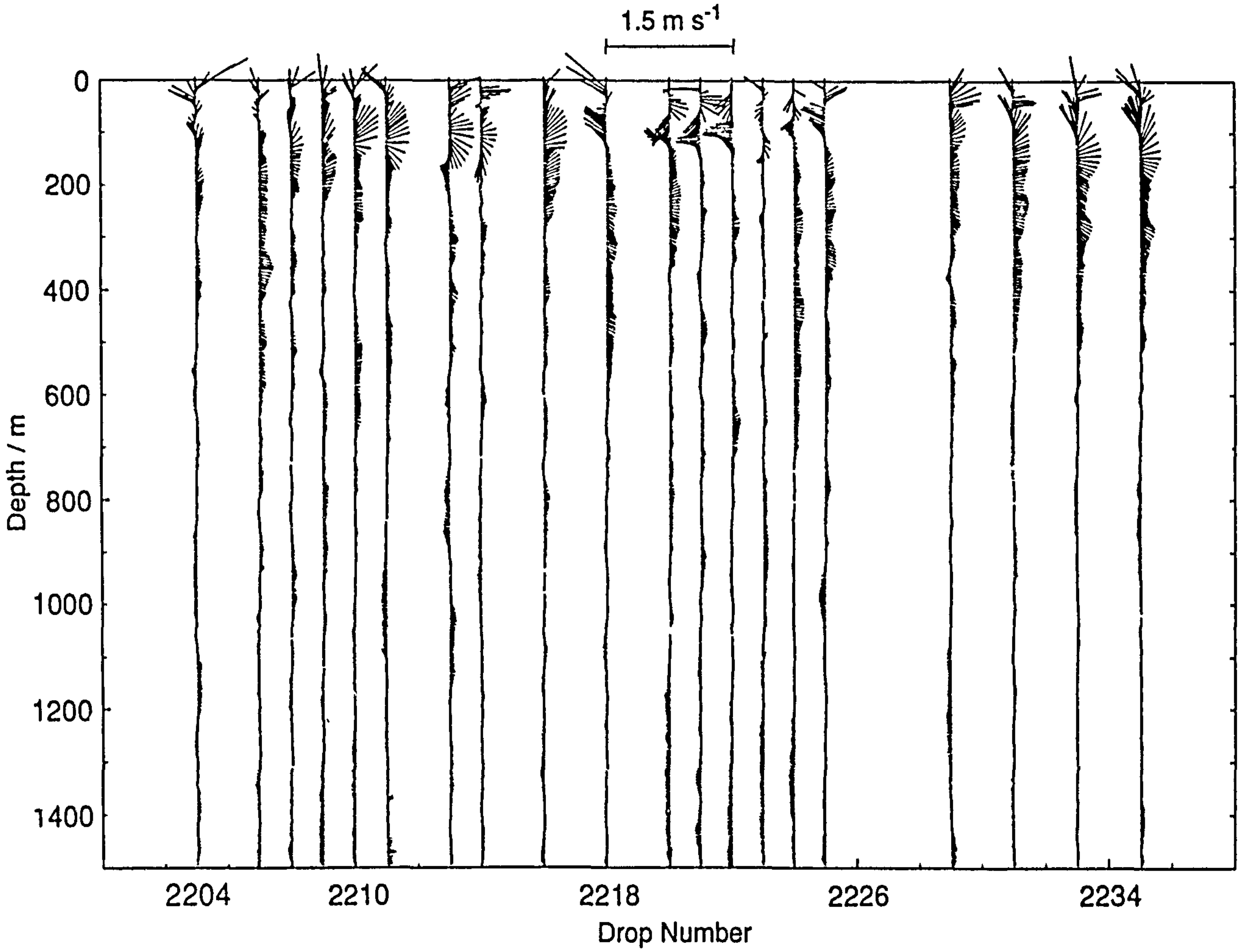


Figure 9. AXCP profiles from 25 October 1987. North is up. Note horizontally coherent velocity features at about 110–150 m.

A number of scatterometer flights were made from 25 October to 13 November by a NASA C-130 aircraft based in Seattle.

From 21 October to 21 November, measurements of shear and microstructure, near-surface dynamics, and atmospheric turbulence were made from CSS *Parizeau*. Radiosonde data were taken and relayed to the meteorological office. The microstructure measurements were easily made in winds up to 35 knots. The remainder of the Lagrangian buoys (10) were deployed to fill a gap that had developed in the drifting array.

On 19 November, the NOAA P-3 crew returned to Seattle, and the aircraft was operational a day later.

On 21 November another pre-storm flight was made in anticipation of a strong storm the next day. The flight pattern (Figure 10) was nearly identical to that used on 25 October. The success rate was much higher, apparently because of the improved launch procedures. Once again, however, the storm the next day was not as strong as predicted, and no further flights were made. The idea of pre-storm flights was therefore abandoned because of the inaccuracy of the weather predictions.

The flight on 1 December was the first of a series during a period that included two strong storms. Winds of 60 knots existed in a band on the southwestern side of an intense low. Guided by Dr. Mel Shapiro (NOAA), who had considerable experience flying in such systems, we anticipated a sharp transition between the 60 knot winds and much lower winds. Meteorological dropsondes dropped from 18,000 ft were used to delineate this transition on a transect southward from the center of the low. Slowfall AXCPs were

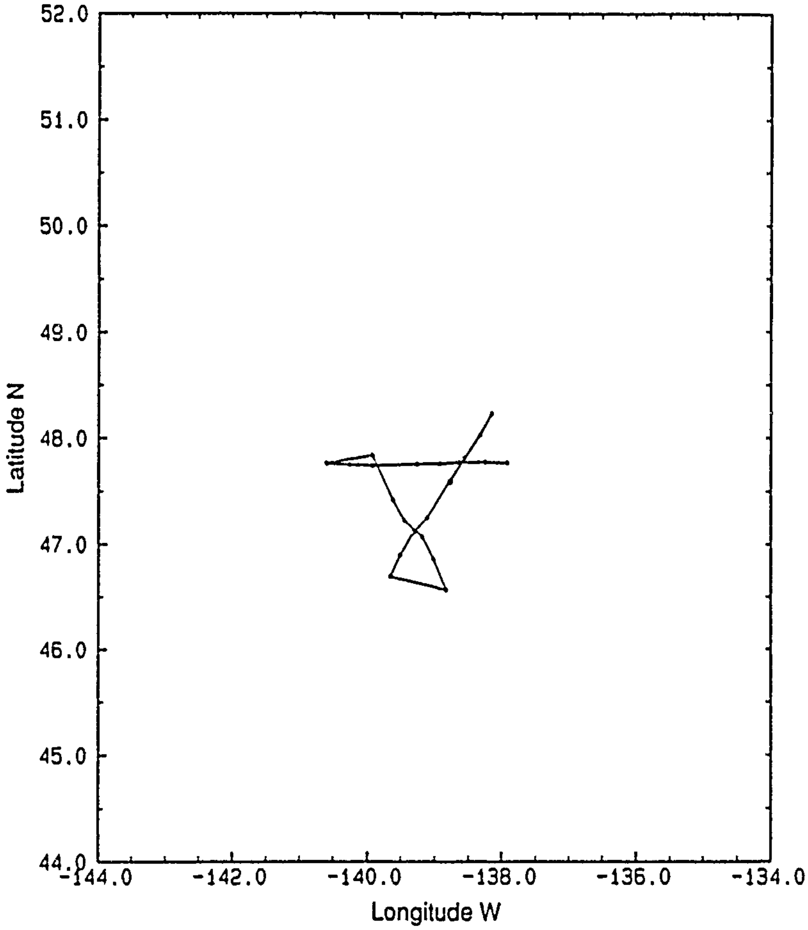


Figure 10. Flight track for 21/22 November 1987. Dots indicate successful AXCP drops.

then dropped from 5000 ft across the transition zone while going north. The flight track was limited to east of 137.5°W because of military exercises in the area. Although this excluded operations over the moored array, it allowed the AXCP measurements to be made in roughly the center of the drifter array.

The flight track is shown in Figure 11. The first profile in Figure 12 is a slowfall AXCP from this flight. The surface wave signal, strongly attenuated by filtering, is seen in the upper 150 m of the profile. Other examples of data are shown by Osse et al. (1988) and Horgan et al. (1989).

The next day, a flight was undertaken to resurvey (with slowfall AXCPs) the area surveyed the previous day to determine the time evolution of the storm-forced currents.

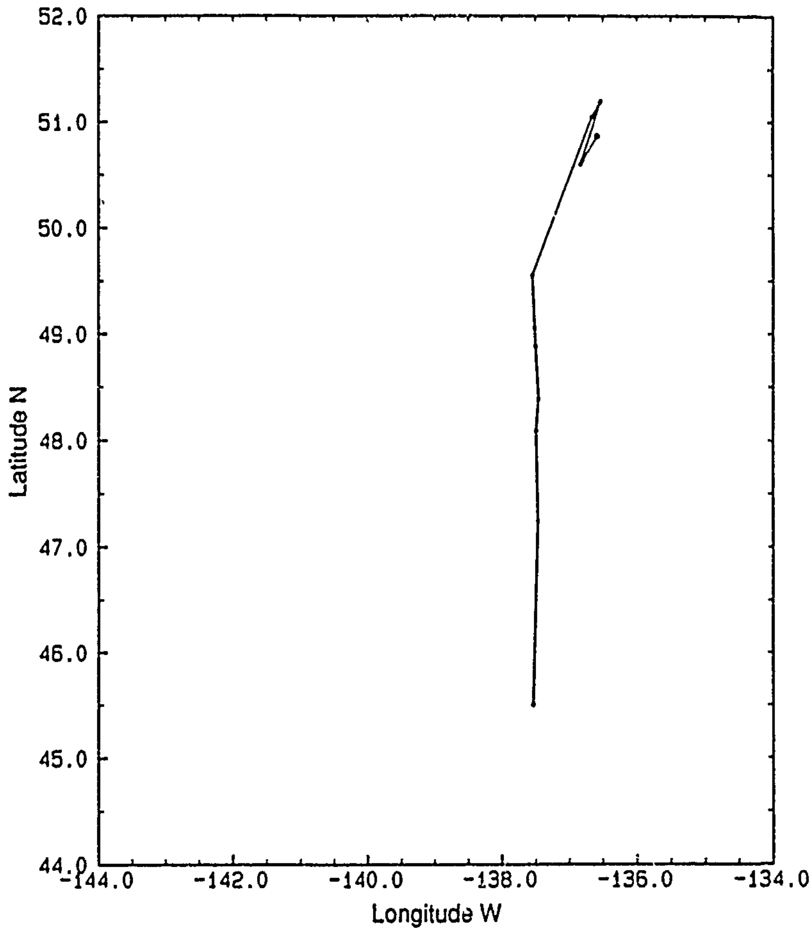


Figure 11. Flight track for 1 December 1987. Dots indicate successful AXCP drops.

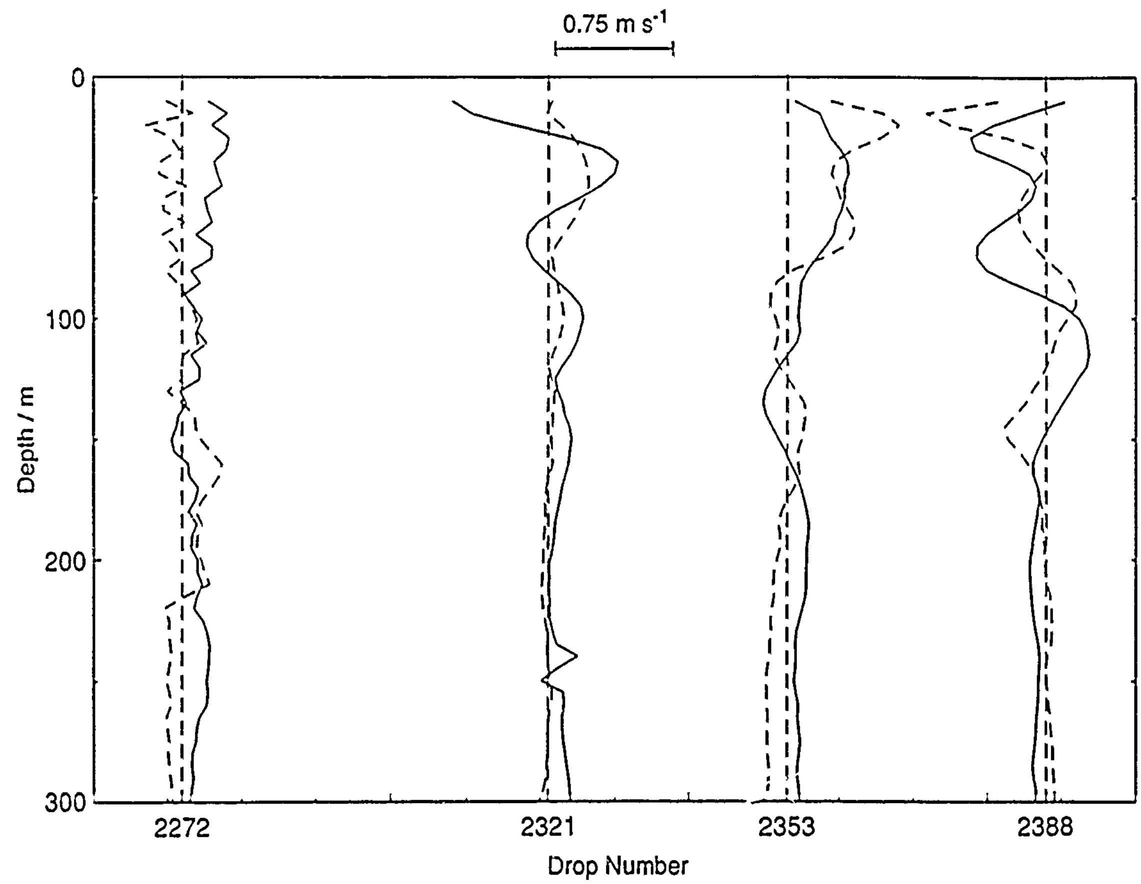


Figure 12. AXCP profiles at center of "X" array; from flights on (left to right) 1, 2, 4 and 5/6 December. The leftmost profile is from a slowfall AXCP; the rest are from regular AXCPs. Note filtering of surface waves by the slowfall unit (2272) and strong shear at mixed layer base during 4 December storm (unit 2353).

In addition, a detailed spatial survey of the area in the center of the drifter array was made with regular AXCPs. The flight track is shown in Figure 13. The wind was nearly calm, in marked contrast to the previous night. The second profile in Figure 12 is from this survey.

No flight was made on 3 December, to allow further evolution of the oceanic inertial currents. Weather forecasts predicted a strong front over the array on 4 December. A flight was therefore planned that combined a continuation of the AXCP time series with meteorological transects of the front.

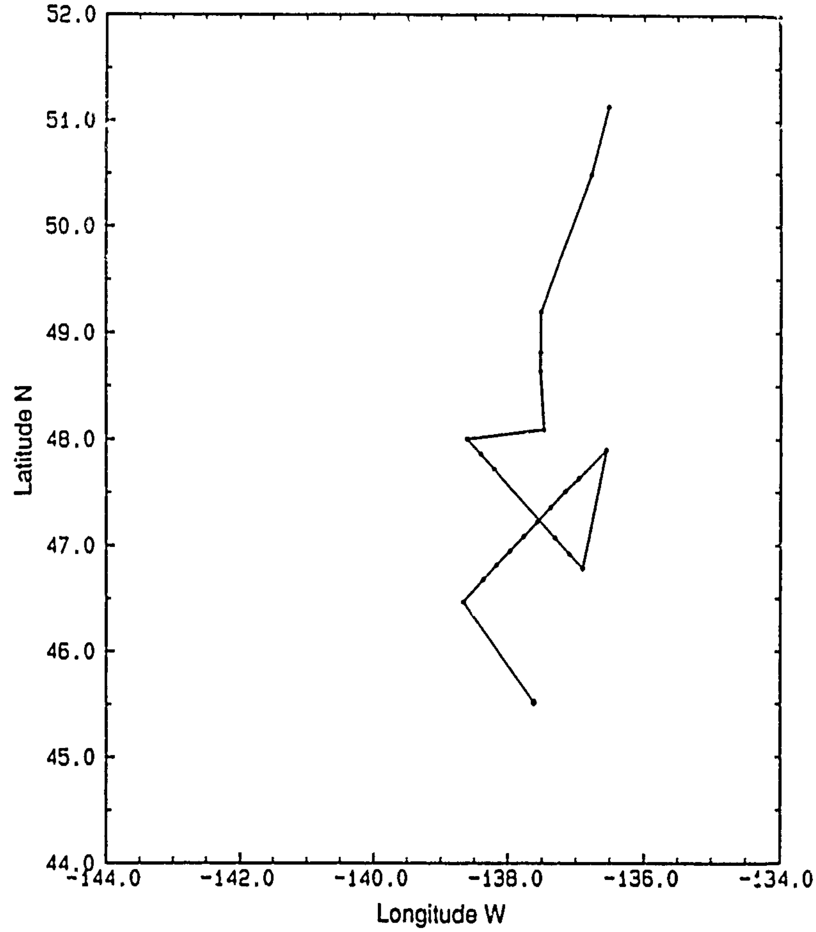


Figure 13. Flight track for 2 December 1987. Dots indicate successful AXCP drops.

The approximate track of the flight is shown in Figure 14; Figure 15 shows the same track along with the location of other OCEAN STORMS measurements. On the left is the approximate location of an occluded front at 0600Z on 5 December. Winds ahead of the front and over most of the experimental area were in excess of 60 knots; those behind were about 35 knots. The front moved to the right at about 30 knots, passing over the array in about 6 hours.

In Figure 15, the moored array is located under the front at about 47.5°N. The wiggly lines are 1-day paths of the drift buoys in this area; the buoy marked with a "T" at the end has a thermistor chain also. Tracks similar to these were received every day at APL and were used in the flight planning. The third profile in Figure 12 is from the 4 December survey. Note how the mixed layer moves to the northeast at about 0.5 m s^{-1}

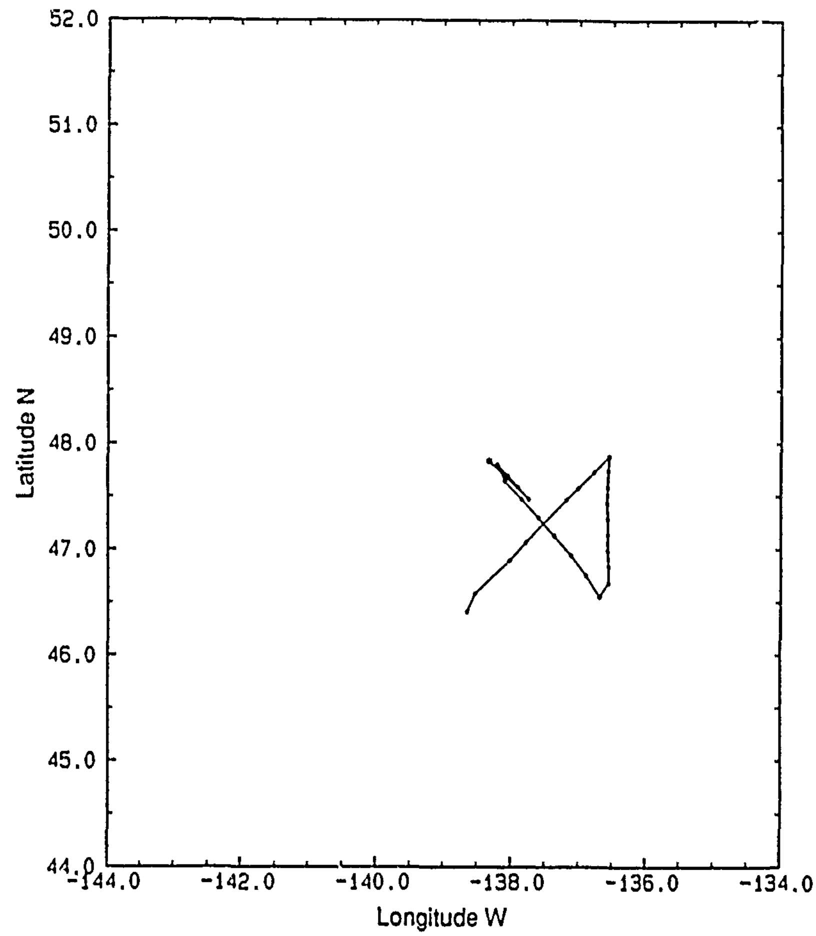


Figure 14. Flight track for 4/5 December 1987. Dots indicate successful AXCP drops.

relative to the underlying water. This is in approximately the same direction as the wind stress, suggesting that we are observing the wind-forced motion of the mixed layer.

The flight on 5/6 December was the last in the AXCP program. It was designed to resurvey the experimental region 5 days after the first storm and 1 day after the second storm. The flight was originally timed to occur exactly 1.5 inertial periods after the previous flight to best extract the inertial component of velocity. However, a problem with the aircraft delayed the flight by several hours. After completion of the basic survey, the few remaining AXCPs were used to survey the area near the center of the pattern, where a small-scale, energetic velocity feature was apparent. The flight pattern is shown in Figure 16. A profile from this flight is shown on the right in Figure 12.

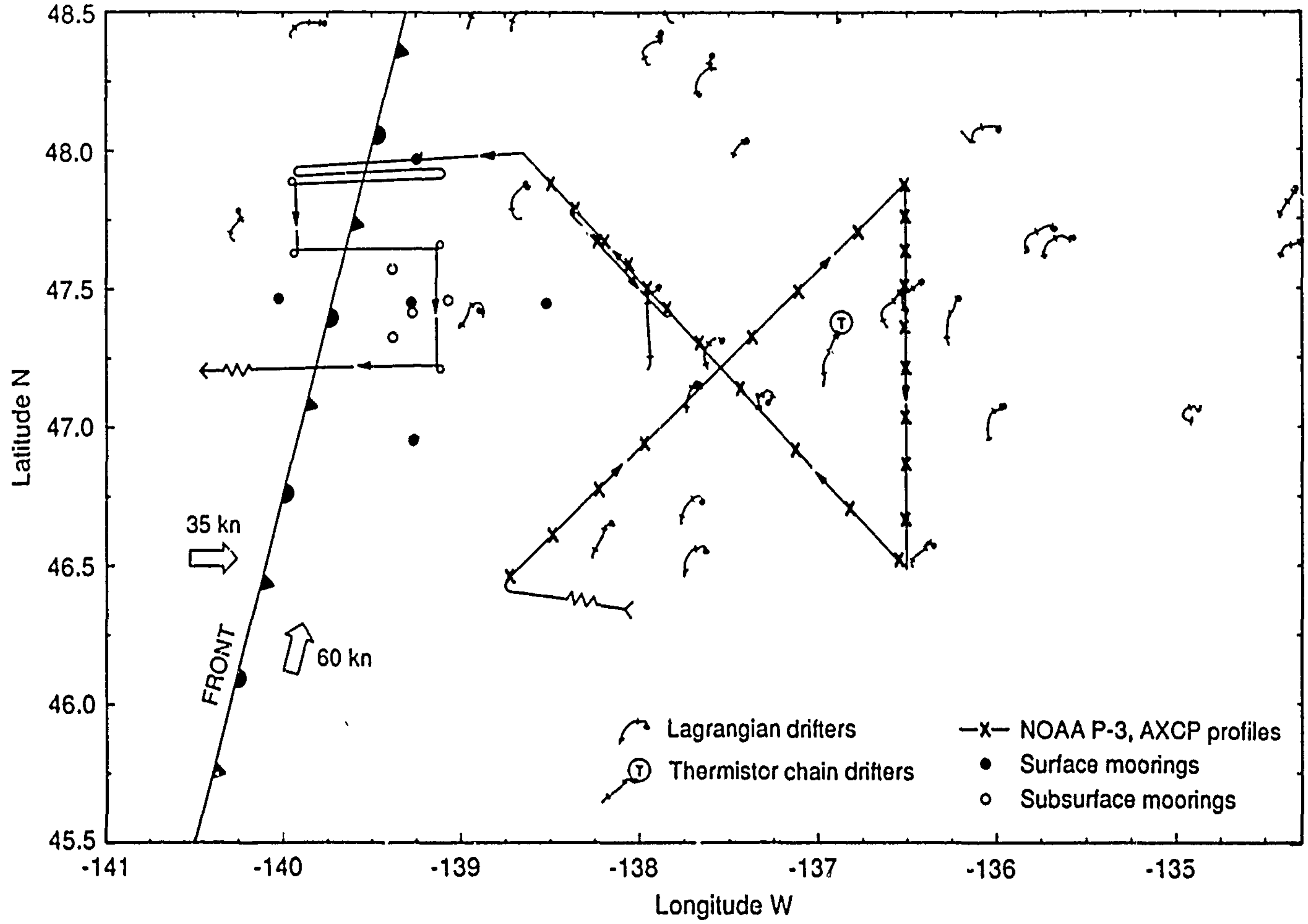


Figure 15. OCEAN STORMS experimental array during the storm on 4/5 December. An occluded warm front over the moored array separates a region of 60-knot winds from one of 35-knot winds. An array of mixed-layer drifters (tadpoles) is centered east of the moored array. A thermistor chain buoy is indicated by the "T". The solid line shows the AXCP flight track on 4 December, and the x's mark successful drops.

Tables IV and V summarize the information on each of the AXCP drops. The navigational information is approximate. It was taken from the in-flight Loran-C, when available; otherwise it was from the Omega/INS system corrected by the most recent Loran-C data.

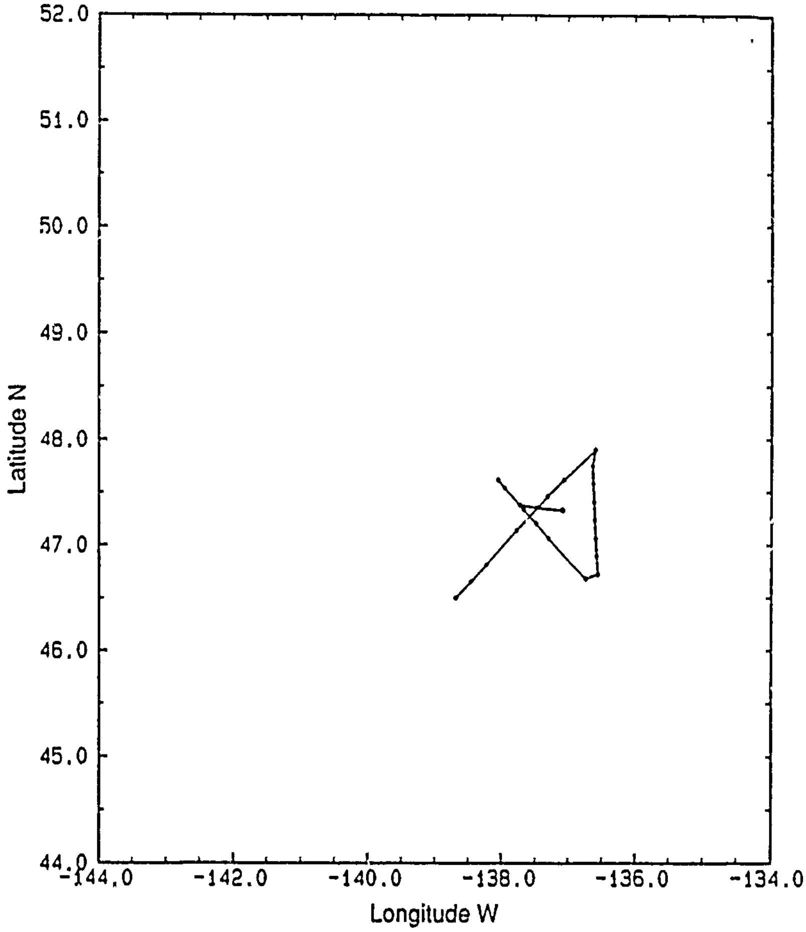


Figure 16. Flight track for 5/6 December 1987. Dots indicate successful AXCP drops.

Table IV. AXCP drops during OCEAN STORMS, 1987.

Drop No.	Sequence in Flight	Serial No.	Real Time No.	Computer Time	RF On[a]	AF On	Log Time
2201	1 (23 Oct)	8177	1036_1	19:09:00	0	0	19:25:xx
2202	2	364	1038_2	19:09:00	0	0	19:20:xx
2203	3	8240	1036_3	19:09:00	0	0	19:25:xx
2204	1 (25 Oct)	8191	0	19:33:11	35:ff	0	19:33:05
2205	2	82	1404_2	19:38:33	39:37	0	19:38:36
2206	3	8241	0	19:42:32	44:ff	0	19:42:34
2207	4	866	1452_1	19:46:33	47:39	0	19:46:40
2208	5	832	1476_2	19:50:33	51:38	0	19:50:33
2209	6	8227	1500_3	19:54:33	55:35	56:19	19:54:33
2210	7	883	1524_1	19:58:33	59:33	00:20	19:58:33
2211	8	83	1547_2	20:02:33	03:34	04:18	20:02:33
2212	9	387	0	20:06:32	08:ff	0	20:06:34
2213	10	8192	1688_1	20:25:53	26:55	27:41	20:25:54
2214	11	8107	1712_2	20:29:56	30:57	31:43	20:30:00
2215	12	377	0	20:33:52	35:ff	0	20:33:52
2216	13	864	1760_1	20:37:52	38:54	39:39	20:37:53
2217	14	891	0	20:41:52	43:ff	0	20:41:53
2218	15	8230	1811_3	20:46:29	47:30	48:17	20:46:29
2219	16	852	0	20:50:28	52:ff	0	20:50:29
2220	17	833	1859_2	20:54:29	55:30	56:15	20:54:29
2221	18	383	1883_3	20:58:28	59:29	00:15	20:58:29
2222	19	871	1907_1	21:02:28	03:29	04:12	20:02:29
2223	20	816	2071_2	21:29:48	31:03	31:36	21:29:49
2224	21	8229	2095_3	21:33:48	34:49	35:33	21:33:49
2225	22	8171	2119_1	21:37:48	38:48	39:35	21:37:49
2226	23	8154	0	21:41:48	42:48	44:ff	21:41:49
2227	24	389	0	21:0	47:ff	0	21:45:49
2228	25	8214	0	21:49:48	51:ff	0	21:49:49
2229	26	817	2277_2	22:04:14	05:14	05:58	22:04:15
2230	27	434_626	0	22:08:14	09:ff	0	22:08:16
2231	28	8152	2333_1	22:13:29	14:30	15:17	22:13:30
2232	29	8100	0	22:17:28	18:ff	0	22:17:30
2233	30	8235	2416_3	22:26:59	29:xx	0	22:27:00x
2234	31	658	0	22:27:01	29:ff	0	22:27:02x
2235	32	8135	2417_2	22:27:03	29:xx	0	22:27:04
2236	1 (21 Nov)	877	1338_1	22:56:26	57:29	58:11	22:56:30
2237	2	814	1368_2	23:01:26	02:34	03:09	23:01:27
2238	3	8231	1396_3	23:06:12	07:14	07:59	23:06:17
2239	4	8158	1425_1	23:11:01	12:03	12:47	23:11:06
2240	5	896	1455_2	23:15:53	17:xx	0	23:15:57
2241	6	8201	0	23:20:54	21:54	23:ff	23:20:58
2242	7	8181	1513_1	23:25:29	26:36	27:20	23:25:34
2243	8	827	1540_2	23:30:06	31:10	31:55	23:30:10
2244	9	8257	1570_3	23:35:11	36:13	36:57	23:35:15

[a]Notation: ff indicates failure, xx indicates approximate time, 0 means no recorded time.

Table IV, cont.

Drop No.	Sequence in Flight	Serial No.	Real Time No.	Computer Time	RF On[a]	AF On	Log Time
2245	10 (22 Nov)	8156	0	00:02:38	03:ff	0	00:02:40
2246	11	811	0	00:06:03	07:ff	0	00:06:05
2247	12	421	1770_3	00:08:27	09:29	10:16	00:08:34
2248	13	8160	0	00:11:56	13:00	13:43	00:12:00
2249	14	8199	1816_2	00:16:04	17:08	17:53	00:16:08
2250	15	8223	1838_3	00:19:48	20:50	21:34	00:19:51
2251	16	8175	1860_1	00:23:29	24:31	25:15	00:23:31
2252	17	894	1884_2	00:27:26	28:30	29:14	00:27:28
2253	18	8265	1917_3	00:32:52	33:54	34:40	00:32:54
2254	19	634	2146_1	01:11:07	12:10	12:56	01:11:10
2255	20	89	2170_2	01:15:06	16:08	16:53	01:15:10
2256	21	8206	2195_3	01:19:12	20:18	21:02	01:19:14
2257	22	892	2214_1	01:22:24	23:27	24:11	01:22:26
2258	23	810	0	01:26:10	27:15	28:ff	01:26:13
2259	24	8187	0	01:30:23	0	0	01:30:26
2260	25	893	0	01:32:xx	33:ff	0	01:32:12
2261	26	8178	2283_2	01:33:56	35:01	35:47	01:33:59
2262	27	8203	2310_3	01:38:26	39:28	40:12	01:38:28
2263	28	861	2333_1	01:42:19	43:25	44:06	01:42:22
2264	29	650	0	02:26:26	27:xx	0:ff	02:25:48
2265	30	8204	2598_3	02:26:28	27:xx	0	0
2266	31	8123	2598_1	02:26:30	27:xx	0	0
2267	1 (1 Dec)	656	2506_3	15:23:16	25:06	25:47	15:23:19
2268	2	843	0	15:38:02	39:47	40:xx	15:38:05
2269	3	648	0	15:41:13	42:34	43:ff	15:41:14
2270	4	429_621	0	15:45:23	46:20	48:ff	15:45:24
2271	5	635	0	15:48:43	50:ff	0	15:48:44
2272	6	436_628	2664_2	15:50:32	51:31	52:11	15:50:34
2273	7	655	2753_3	16:05:26	06:22	07:07	16:05:28
2274	8	699	0	16:08:54	10:ff	0	16:08:56
2275	9	438_630	2785_2	16:10:45	11:45	12:27	16:10:15
2276	11	847	0	16:14:20	16:ff	0	16:14:22
2277	10	652	0	16:16:32	17:35	0:ff	16:16:34
2278	26	430_622	0	16:19:xx	20:ff	0	16:19:18
2279	12	640	2847_2	16:20:53	21:53	22:34	16:20:55
2280	13	659	2868_3	16:24:26	25:27	26:08	16:24:28
2281	14	638	0	16:27:55	29:ff	0	16:27:57
2282	29	840	0	16:29:43	30:46	ff	16:29:45
2283	15	411	0	16:32:xx	32:48	ff	16:31:43
2284	16	395	2926_3	16:34:13	35:12	35:53	16:34:13
2285	17	347	0	16:37:28	38:ff	0	16:37:30
2286	20	329	0	16:39:24	40:ff	0	16:39:26
2287	18	399	0	17:02:22	0:ff	0	17:02:24
2288	23	875	3096_1	17:02:32	04:xx	4:24x	17:02:31
2289	19	651	3109_3	17:04:57	05:57	06:30	17:04:57

Table IV, cont.

Drop No.	Sequence in Flight	Serial No.	Real Time No.	Computer Time	RF On[a]	AF On	Log Time
2290	3A	849	0	17:37:16	0	0	17:37:15
2291	1B	8101	3303_2	17:37:18	0	0	17:37:20
2292	2C	325	0	17:37:21	0	0	17:37:24
2293	22	645	3314_3	17:38:57	0	0	17:38:57
2294	6D	870	0	17:39:54	0	0	17:39:54
2295	9E	407	3334_1	17:42:23	0	0	17:42:25
2296	SM (2 Dec)	653	1_3	16:29:38	0	31:31	16:29:39
2297	SK	435_627	0	16:47:22	48:xx	0	16:47:22
2298	SL	423_615	1342_[illegible]	16:49:26	50:27	51:10	16:49:27
2299	SG	433_625	0	17:05:15	06:53	07:40	17:05:15
2300	SJ	644	0	17:08:54	10:31	11:13	17:08:55
2301	SB	409	0	17:12:02	0:ff	0	17:12:04
2302	SD	431_625	228_3	17:14:49	16:24	17:08	17:14:49
2303	SF	646	1596_2a17:21:10	22:49	23:ff	17:21:10	
2304	SC	642	1596_2b17:24:03	26:xx	0:ff	17:24:04	
2305	SA	424_616	398_3	17:44:43	45:40	46:25	17:44:45
2306	A	396	1767_2	18:00:25	01:29	02:11	18:00:27
2307	B	8260	510_3	18:03:37	04:37	05:26	18:03:37
2308	C	882	1805_1	18:06:52	07:53	08:32	18:06:53
2309	D	8108	0	18:10:05	11:ff	0	18:10:06
2310	SI	637	0	18:17:57	19:07	19:57	18:17:58
2311	E	8269	616_3	18:21:14	0	0	18:21:15
2312	F	855	1912_1	18:24:28	25:xx	26:20	18:24:28
2313	G	8248	1931_2	18:27:43	28:51	29:35	18:27:44
2314	H	8259	0	18:30:56	33:ff	0	18:30:58
2315	I	8117	0	18:34:13	35:ff	0	18:34:13
2316	J	86	0	18:39:14	0:ff	0	18:39:15
2317	K	8219	933_3	19:14:14	15:15	15:55	19:14:15
2318	L	8120	0	19:17:25	0:ff	0	19:17:26
2319	M	812	2248_2	19:20:42	21:33	22:20	19:20:43
2320	N	8261	991_3	19:23:56	24:46	25:32	19:23:57
2321	R	8103	2288_1	19:27:23	28:16	29:03	0
2322	P	830	2307_2	19:30:36	31:30	32:16	19:30:37
2323	Q	8182	1051_3	19:33:55	34:45	35:32	19:33:54
2324	SE	359	2348_1	19:37:07	38:01	38:45	19:37:09
2325	S	834	2366_2	19:40:22	41:14	41:57	19:40:23
2326	T	8212	1109_3	19:43:37	44:29	45:18	19:43:39
2327	O	406	2415_1	19:48:30	49:24	50:08	19:48:32
2328	SH	657	2537_2	20:08:28	09:18	10:03	20:08:30
2329	0 (4 Dec)	829	1496_2	21:50:44	52:xx	52:38	21:50:45
2330	1	8161	1515_3	21:53:57	54:59	55:44	21:53:57
2331	2	853	0	21:57:18	58:23	59:06	21:57:19
2332	3	8106	1555_2	22:00:39	01:43	02:27	22:00:40
2333	4	8242	1575_3	22:03:57	04:57	05:42	22:03:57
2334	5	401	0	22:07:17	08:ff	0	22:07:17
2335	6	828	0	22:10:37	11:ff	0	22:10:38

Table IV, cont.

Drop No.	Sequence in Flight	Serial No.	Real Time No.	Computer Time	RF On[c]	AF On	Log Time
2336	7	8224	1626_3	22:12:27	13:27	14:13	22:12:26
2337	8	862	1640_1	22:14:47	15:53	16:36	22:14:47
2338	9	88	1660_2	22:18:07	19:11	19:54	22:18:08
2339	10	8202	1679_3	22:21:16	22:20	23:03	22:21:17
2340	11	8104	1725_1	22:28:57	29:58	30:44	22:28:58
2341	12	889	1745_2	22:32:21	33:24	34:xx	22:32:22
2342	13	8208	1765_3	22:35:37	36:xx	37:22	22:35:38
2343	14	410	1785_1	22:38:55	39:56	40:39	22:38:56
2344	15	895	1805_2	22:42:15	43:30	44:02	22:42:15
2345	16	8217	1825_3	22:45:37	46:40	47:24	22:45:38
2346	17	393	1845_1	22:48:56	49:57	50:42	22:48:56
2347	18	8176	1865_2	22:52:16	53:21	54:05	22:52:17
2348	19	8236	0	22:55:38	57:ff	0	22:55:38
2349	20	8110	1896_1	22:57:32	59:xx	59:18	22:57:33
2350	21	921	1916_2	23:00:50	02:xx	02:35	23:00:47
2351	22	8228	1936_3	23:04:07	05:10	05:52	23:04:08
2352	23	878	1956_1	23:07:33	08:33	09:17	23:07:34
2353	24	8102	1976_2	23:10:47	11:49	12:xx	23:10:48
2354	25	8205	1996_3	23:14:07	15:13	15:54	23:14:07
2355	26	860	2016_1	23:17:26	18:31	19:15	23:17:26
2356	27	818	2041_2	23:21:34	22:38	23:23	23:21:34
2357	28	84	2061_3	23:24:57	26:06	26:46	23:24:58
2358	29	8195	2081_1	23:28:16	29:xx	30:03	23:28:17
2359	30	873	2102_2	23:31:47	32:48	33:32	23:31:48
2360	31	8267	2153_3	23:40:25	41:26	42:07	23:40:26
2361	32	400	0	23:43:33	44:34	45:ff	23:43:34
2362	33	8193	0	23:45:45	47:ff	0	23:45:46
2363	34	8258	0	23:48:00	49:ff	0	23:47:59
2364	1 (6 Dec)[b]	8169	2018_2	02:25:28	26:40	27:25	02:25:28
2365	2	8237	2036_3	02:28:44	29:44	30:29	02:28:43
2366	3	867	2057_1	02:32:07	33:08	33:54	02:32:08
2367	4	897	0	02:35:30	36:28	38:ff	02:35:27
2368	5	420	2097_3	02:38:45	39:47	40:32	02:38:45
2369	6	8136	0	02:42:04	43:05	44:ff	02:42:05
2370	7	888	2136_2	02:45:24	46:25	47:08	02:45:25
2371	8	8233	2157_3	02:48:45	49:45	50:38	02:48:45
2372	9	857	0	02:52:05	53:ff	0	02:52:06
2373	10	880	2194_2	02:55:03	56:xx	56:49	02:55:04
2374	11	8200	2230_3	03:00:56	01:58	02:43	03:00:56
2375	12	850	2250_1	03:04:15	05:18	06:02	03:04:16
2376	13	890	2270_2	03:07:47	08:50	09:29	03:07:48
2377	14	398	2291_3	03:11:06	12:10	12:54	03:11:07
2378	15	8186	2312_1	03:14:28	15:38	16:27	03:14:28
2379	16	8105	2331_2	03:17:46	18:48	19:33	03:17:46

[b] Flight began on 5 December; first AXCP drop was on 6 December.

Table IV, cont.

Drop No.	Sequence in Flight	Serial No.	Real Time No.	Computer Time	RF On[a]	AF On	Log Time
2380	17	432_624	2351_3	03:21:10	22:11	22:56	03:21:10
2381	18	405	0	03:24:53	25:55	27:ff	03:24:53
2382	19	835	0	03:29:23	30:26	31:09	03:29:24
2383	20	8222	2420_3	03:32:50	33:41	34:26	03:32:51
2384	21	402	0	03:36:06	36:55	38:ff	03:36:07
2385	22	8198	0	03:38:20	40:ff	0	03:38:21
2386	35	899	0	03:40:14	41:xx	42:ff	03:40:15
2387	23	8234	2478_3	03:42:30	43:19	44:06	03:42:30
2388	24	858	2498_1	03:45:56	46:46	47:29	03:45:57
2389	25	813	2519_2	03:49:15	50:05	50:50	03:49:16
2390	26	8239	0	03:52:37	53:ff	0	03:52:37
2391	34	885	2548_3	03:54:08	55:xx	55:42	03:54:09
2392	27	8130	2559_1	03:55:56	56:45	57:31	03:55:56
2393	28	831	0	03:59:16	00:06	01:ff	03:59:17
2394	29	8238	0	04:03:39	04:27	05:ff	04:03:39
2395	36	367	0	04:08:14	09:05	10:13	04:08:15
2396	31	8132	2725_2	04:23:41	24:30	25:14	04:23:42
2397	32	8263	2743_3	04:26:36	27:30	28:13	04:26:38
2398	30	639	0	04:28:xx	29:06	30:ff	04:28:17
2399	33	886	2769_2	04:30:53	31:46	32:31	04:30:58

Table V. AXCP drop locations.

Drop No.	Sequence in flight	RF Channel slow/fast[a]	Flight	Latitude N		Longitude W	
2201	1	12r	23 Oct	00	00	00	00
2202	2	14s	23 Oct	00	00	00	00
2203	3	16r	23 Oct	00	00	00	00
2205	2	14r	25 Oct	47	45.0	138	23.9
2207	4	12r	25 Oct	47	45.2	139	1.6
2208	5	14r	25 Oct	47	44.8	139	20.6
2209	6	16r	25 Oct	47	44.7	139	40.1
2210	7	12r	25 Oct	47	45.0	140	0.5
2211	8	14r	25 Oct	47	45.4	140	20.1
2213	10	12r	25 Oct	48	10.0	140	13.3
2214	11	14r	25 Oct	47	59.7	140	4.3
2216	13	12r	25 Oct	47	38.1	139	49.0
2218	15	16r	25 Oct	47	14.1	139	30.1
2220	17	14r	25 Oct	46	55.2	139	5.1
2221	18	16r	25 Oct	46	43.9	138	56.9
2222	19	12r	25 Oct	46	32.1	138	48.5
2223	20	14r	25 Oct	46	38.9	139	41.1
2224	21	16r	25 Oct	46	52.5	139	29.3
2225	22	12r	25 Oct	47	5.7	139	16.6
2229	26	14r	25 Oct	48	0.0	138	26.6
2231	28	12r	25 Oct	47	35.4	138	44.8
2233	30	16r	25 Oct	47	16	139	7.1
2235	32	14r	25 Oct	47	16	139	7.1
2236	1	12m	21 Nov	47	46.08	137	55.5
2237	2	14m	21 Nov	47	46.45	138	15.3
2238	3	16m	21 Nov	47	46.3	138	38.9
2239	4	12m	21 Nov	47	45.6	138	55.4
2240	5	14m	21 Nov	47	45.3	139	16.4
2242	7	12m	21 Nov	47	44.4	139	56.2
2243	8	14m	21 Nov	47	45.1	140	15.8
2244	9	16m	21 Nov	47	45.9	140	36.4
2247	12	16m	22 Nov	47	50.3	139	56.1
2249	14	14m	22 Nov	47	25.1	139	37.1
2250	15	16m	22 Nov	47	13.5	139	27.1
2251	16	12m	22 Nov	47	4.2	139	11.5
2252	17	14m	22 Nov	46	51.8	139	1.5
2253	18	16m	22 Nov	46	34.2	138	49.3
2254	19	12r	22 Nov	46	41.9	139	39.6
2255	20	14m	22 Nov	46	54.0	139	30.6
2256	21	16m	22 Nov	47	6.8	139	19.3
2257	22	12r	22 Nov	47	15.0	139	7.1
2261	26	14m	22 Nov	47	48.6	138	33.7
2262	27	16r	22 Nov	48	1.8	138	19.2

[a] r = regular, m = regular with modified wind flap, s = slowfall.

Table V, cont.

Drop No.	Sequence in flight	RF Channel slow/fast[a]	Flight	Latitude N		Longitude W	
2263	28	12r	22 Nov	48	13.7	138	8.8
2265	30	16r	22 Nov	47	35.4	138	46.3
2266	31	12r	22 Nov	47	35.4	138	46.3
2267	1	16s	1 Dec	45	30.1	137	32.6
2272	6	14s	1 Dec	47	14.3	137	28.1
2273	7	16s	1 Dec	48	05.1	137	29.8
2275	9	14s	1 Dec	48	23.2	137	27.5
2279	12	14s	1 Dec	48	52.9	137	30.2
2280	13	16s	1 Dec	49	03.3	137	31.1
2284	16	16s	1 Dec	49	33.1	137	33.1
2288	23	12s	1 Dec	51	02.7	136	39.9
2289	19	16s	1 Dec	51	11.3	136	32.1
2291	1B	14r	1 Dec	50	36.1	136	50.1
2293	22	16s	1 Dec	50	38.2	136	48.3
2295	9E	12r	1 Dec	50	51.8	136	35.1
2296	SM	16s	2 Dec	51	07.9	136	31.8
2298	SL	14s	2 Dec	50	29.4	136	47.4
2302	SD	16s	2 Dec	49	11.4	137	31.6
2303	SF	14s	2 Dec	48	48.6	137	32.0
2304	SC	14s	2 Dec	48	38.1	137	32.1
2305	SA	16s	2 Dec	48	05.4	137	28.8
2306	A	14r	2 Dec	48	0.0	138	37.1
2307	B	16r	2 Dec	47	51.6	138	25.0
2308	C	12r	2 Dec	47	42.9	138	12.8
2311	E	16r	2 Dec	47	04.3	137	18.4
2312	F	12r	2 Dec	46	55.3	137	05.9
2313	G	14m	2 Dec	46	47.0	136	54.3
2317	K	16r	2 Dec	47	53.8	136	33.2
2319	M	14r	2 Dec	47	37.8	136	57.8
2320	N	16r	2 Dec	47	30.4	137	9.6
2321	R	12r	2 Dec	47	21.5	137	22.4
2322	P	14r	2 Dec	47	13.2	137	34.6
2323	Q	16r	2 Dec	47	5.0	137	46.4
2324	SE	12s	2 Dec	46	56.9	137	58.6
2325	S	14r	2 Dec	46	48.9	138	10.8
2326	T	16r	2 Dec	46	40.8	138	22.6
2327	O	12r	2 Dec	46	28.0	138	40.3
2328	SH	14s	2 Dec	45	31.0	137	37.2
2329	0	14r	4 Dec	46	24.8	138	39.6
2330	1	16r	4 Dec	46	34.9	138	32.1
2332	3	14r	4 Dec	46	53.9	138	1.2
2333	4	16r	4 Dec	47	4.1	137	46.9
2336	7	16r	4 Dec	47	28.1	137	10.7

Table V, cont.

Drop No.	Sequence in flight	RF Channel slow/fast[a]	Flight	Latitude N		Longitude W	
2337	8	12r	4 Dec	47	34.6	137	0.4
2338	9	14r	4 Dec	47	43.7	136	45.8
2339	10	16r	4 Dec	47	52.8	136	32.2
2340	11	12r	4 Dec	47	44.4	136	33.3
2341	12	14r	4 Dec	47	35.0	136	33.8
2342	13	16r	4 Dec	47	26.1	136	34.5
2343	14	12r	4 Dec	47	17.2	136	33.9
2344	15	14r	4 Dec	47	8.3	136	33.9
2345	16	16r	4 Dec	46	59.0	136	34.0
2346	17	12r	4 Dec	46	50.5	136	33.2
2347	18	14r	4 Dec	46	41.1	136	33.2
2349	20	12r	4 Dec	46	33.2	136	41.3
2350	21	14r	4 Dec	46	45.4	136	53.4
2351	22	16r	4 Dec	46	56.6	137	6.8
2352	23	12r	4 Dec	47	7.8	137	21.7
2353	24	14r	4 Dec	47	17.9	137	35.6
2354	25	16r	4 Dec	47	28.4	137	50.9
2355	26	12r	4 Dec	47	38.6	138	5.7
2356	27	14r	4 Dec	47	47.9	138	12.1
2357	28	16r	4 Dec	47	41.6	138	3.0
2358	29	12r	4 Dec	47	35.3	137	54.2
2359	30	14r	4 Dec	47	28.4	137	44.3
2360	31	16r	4 Dec	47	50.1	138	19.2
2364	1	14r	6 Dec[b]	46	30.2	138	41.4
2365	2	16r	6 Dec	46	39.5	138	27.6
2366	3	12r	6 Dec	46	49.1	138	13.7
2368	5	16r	6 Dec	47	8.5	137	46.3
2370	7	14r	6 Dec	47	27.9	137	18.3
2371	8	16r	6 Dec	47	37.0	137	3.4
2373	10	14r	6 Dec	47	54.2	136	35.5
2374	11	16r	6 Dec	47	45.2	136	38.1
2375	12	12r	6 Dec	47	35.0	136	37.6
2376	13	14r	6 Dec	47	24.5	136	36.7
2377	14	16r	6 Dec	47	14.3	136	36.1
2378	15	12r	6 Dec	47	4.0	136	35.3
2379	16	14r	6 Dec	46	54.0	136	34.4
2380	17	16r	6 Dec	46	43.7	136	33.3
2383	20	16r	6 Dec	46	41.1	136	44.6
2387	23	16r	6 Dec	47	4.1	137	17.5
2388	24	12r	6 Dec	47	12.5	137	29.2
2389	25	14r	6 Dec	47	20.5	137	40.3
2391	34	16r	6 Dec	47	32.7	137	57.0
2392	27	12r	6 Dec	47	37.1	138	3.1
2396	31	14r	6 Dec	47	23.0	137	43.5
2397	32	16r	6 Dec	47	21.3	137	28.3
2399	33	14r	6 Dec	47	20.1	137	4.7

[b]Flight began on 5 December; first AXCP drop was on 6 December.

5. EQUIPMENT PERFORMANCE

5.1 Decay of RF Signal Levels

A typical time history of the RF signal levels received on AXCP channel 14 is shown in Figure 17a for slowfall AXCP drops 2272 and 2274 on 1 December. Seas and winds were high. The first probe was dropped at about time 0. The RF signal appears at about 80 s at a level of about −85 dBm and then decays to about −100 dBm in less than 200 s. The next probe shows a similar pattern. In both cases, the RF signal is noisy, with very common short periods of very low signal level (dropouts).

A second example of the RF signal level is shown in Figure 17b for regular AXCP drop 2325 on 2 December. The sea was glassy calm. The initial signal level is higher, −80 dBm, and there are fewer dropouts. The higher level seems to be characteristic of the regular AXCPs although some have significantly more dropouts than in Figure 17b. The final level is also lower, −110 dB. The sensitivity of the AGC at these levels is poor, so it is not clear if this is a significant measurement.

A final example is shown in Figure 17c for slowfall AXCP 2303, also on 2 December. The levels are lower than for the regular AXCP, even though the sea state is very similar, and are similar to those for the slowfall AXCPs in Figure 17a.

The fact that the slowfall probes have lower RF signal levels than the regular probes probably accounts for their greater problems with radio noise. The decay in RF signal level is close to the −6 dB per octave expected for spherical spreading.

5.2 AXCP Failure Analysis

5.2.1 *Failure Types*

The AXCP failures fall into two main categories: RF failures, when no radio signal was heard from the probe, and AF failures, when a radio signal occurred but something else malfunctioned. These two main categories are subdivided as shown in Table VI.

Previous AXCP drops in another program, mostly in hurricanes (Sanford et al., 1987), had total probe success rates of 50–80%. In those cases, however, the failures were dominantly of the AF type, with RF failures being very rare. Because of this poor

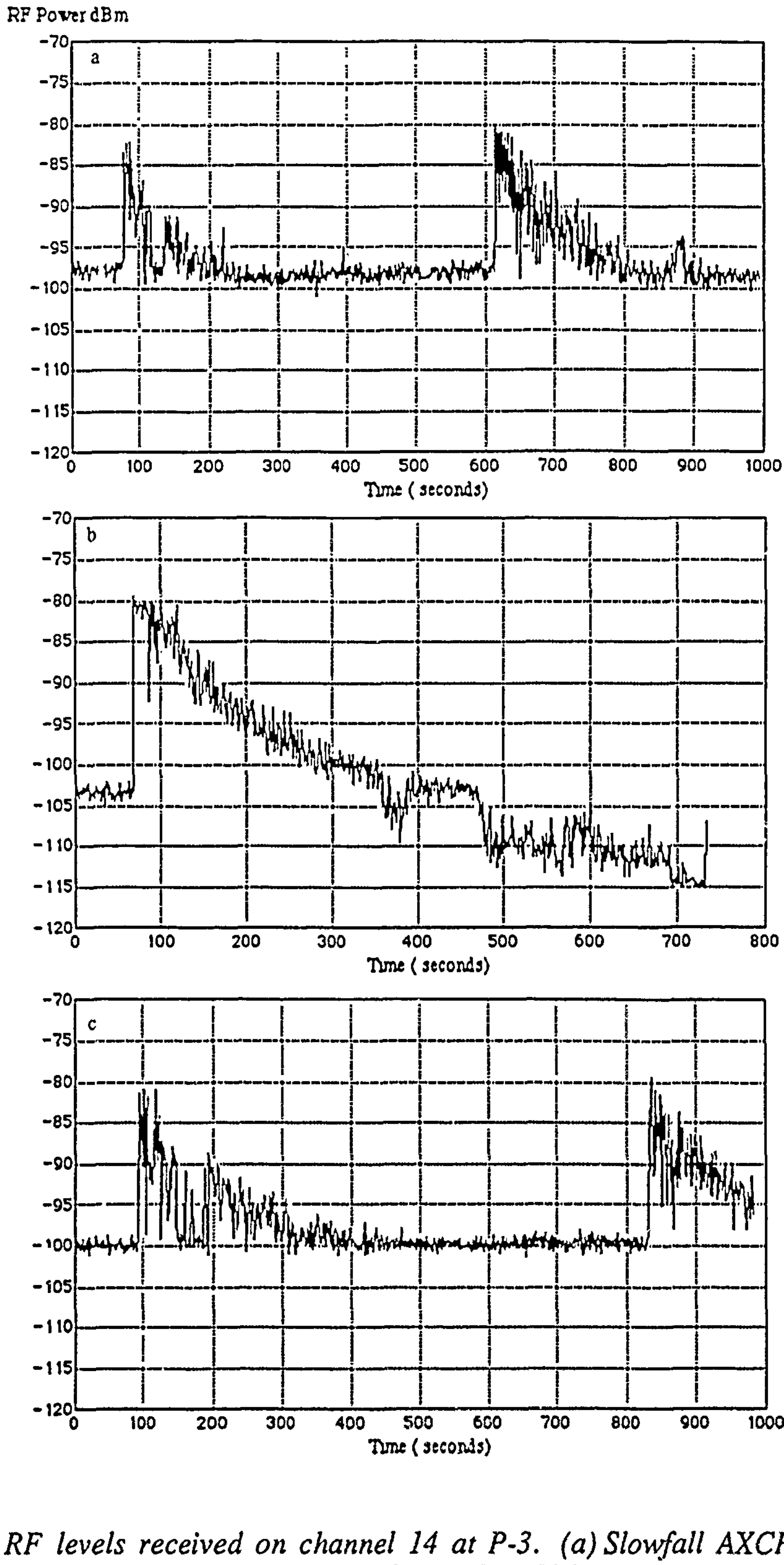


Figure 17. RF levels received on channel 14 at P-3. (a) Slowfall AXCPs 2272 and 2274 on 1 December. (b) Regular AXCP 2325 on 2 December. (c) Slowfall AXCP 2303 and start of AXCP 2304 on 2 December.

Table VI. Types of AXCP failures experienced during OCEAN STORMS.

Type	Cause	Problem Area
RF Failures		
Probe sinks	Inflation bag problem	Bag, seawater battery, electronics, AXCP stuck in launch canister
Radio broken	Mechanical damage	PC board broken
AF Failures		
BT wire broken	Wire cut during shock	Wire spools, AXCP tailcone
Probe broken	AXCP probe broken	AXCP probe
Probe stuck in surface unit	Door jammed No squib fire	Door assembly error, shock PC board, squib, squib wires

success rate, Sippican redesigned the AXCP, paying particular attention to protecting the fragile BT wire. In OCEAN STORMS, however, RF failures were dominant, with AF failures less common. Apparently, a new failure mode was introduced in the process of mostly eliminating the old one.

5.2.2 *Causes of RF Failures*

Figure 18 shows the rate of RF failures as a function of true air speed at time of launch, taken from the 10-s listing of P-3 flight data. Data from the 23 October flight are shown separately for reasons explained later. The failure rate rises from 11% for air speeds less than 205 knots to 28% for air speeds greater than 220 knots. Half of the four probes launched at air speeds greater than 225 knots failed, whereas none of five probes launched at air speeds less than 200 knots failed. It is surprising that such a large change in failure rate occurs for only a 10% change in air speed.

AXCPs launched during the 23 October flight experienced a substantially higher failure rate, as shown in Figure 18. These probes were positioned with the wind flap down in the launch tube but were oriented randomly. On subsequent flights, the wind flap was oriented facing the slip stream, at Sippican's suggestion.

Slowfall AXCPs, although they had a higher total failure rate, had a lower rate of RF failures. Excluding slowfall AXCPs on channel 12, which had a manufacturing defect (Osse et al., 1988), and those used on or before 23 October, slowfall AXCPs

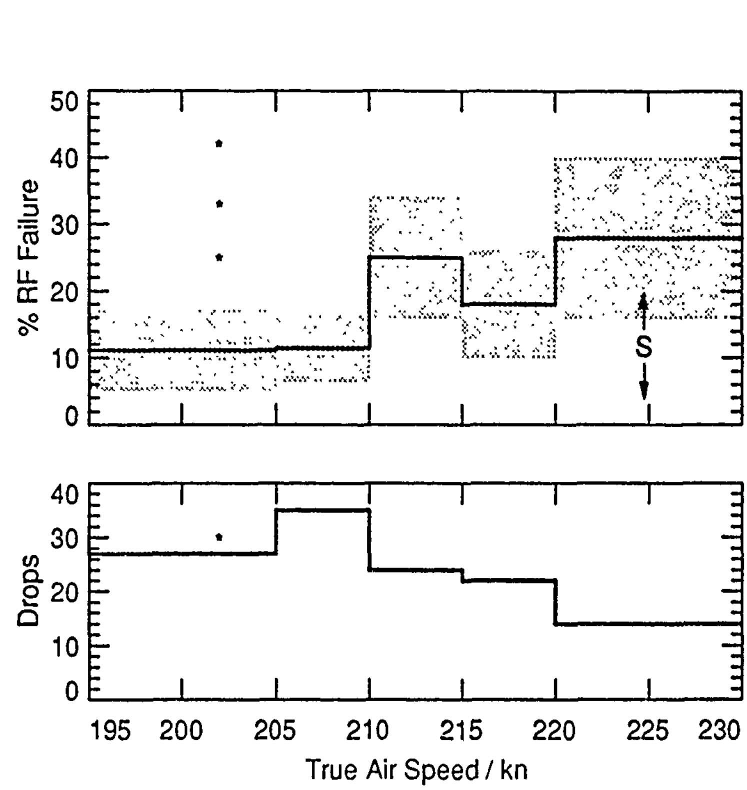


Figure 18. *Upper: Standard AXCP failure rate as a function of wind speed (solid line). One standard deviation is shown by the shaded region (a binomial distribution is assumed). Rates are shown for selected 23 October probes with air speeds less than 215 knots (*) and slowfall probes with air speeds greater than 215 knots (s). Lower: Number of probes used in computation.*

launched at an air speed greater than 215 knots had a failure rate of 12%. There is only a 5% chance that this could occur in a random sample of the regular AXCPs, assuming a 25% failure rate. The packaging of the slowfall AXCPs in the air canister was quite different from that of the regular units, with additional shock protection added.

These observations indicate that the RF failures were associated with something that happened to the AXCP as it exited the P-3 or shortly thereafter, most likely the acceleration. This is supported by the lack of correlation between RF failures and surface wind speed.

5.2.3 *AXCP Behavior During Deployment*

A high-speed video camera (Panasonic model W 3260) was installed in the P-3 for the 21/22 November, 1 December, and 2 December flights. An image was taken every 1/30th of a second, with each image having an effective shutter speed of 1/1000th of a second. The camera's location is shown in Figure 6. It looked down and forward and was adjusted for the best view of the AXCPs as they were deployed. Two orientations were used, with the camera pointing farther aft on 1 and 2 December than on 21/22 November.

Camera images from four characteristic AXCP deployments on 1 and 2 December are shown in Figures 19–22. For reference, the AXCP is about 0.9 m long. On the ground, the camera was approximately 2 m above the runway and saw an approximately rectangular region 2.6 m along the plane's length and 1.8 m across it. The bottom of the image was approximately 30 cm starboard of the plane's centerline, and the left edge was approximately 1.5 m aft of the drop tube.

Figures 19 and 20 show the most typical deployment sequences. A few probe lengths after exiting the tube, the wind flap detaches from the AXCP (Figures 19a and 19b) and pulls out the parachute (Figures 19c, 20a, and 20b). The parachute rotates the probe toward vertical and accelerates it to the left (Figures 19c and 20c).

The causes of AXCP failure are not obvious in these images. The parachutes do not rip apart, nor do the probes disintegrate. There are one or two examples of the parachute cords tangling, but this is not a major failure mode. In contrast, an air deployable drift buoy was observed to disintegrate upon exit from the P-3. We conclude, therefore, that the failures result from some internal failure of the AXCP, presumably due to accelerations upon launch.

A clue to the cause of failure is the great variability in the behavior of the probes upon launch. Some probes (Figure 21) fell away from the aircraft without any evidence of parachute deployment. We believe that the parachute did deploy, since these probes did not reach the surface any sooner than usual. Others (Figure 22) had a fully deployed parachute upon entering the field of view. Analysis of 68 images of the deployment of slowfall (excluding channel 12) and regular AXCPs is shown in Table VII. Probes are classified by whether the parachute is visible in the images and by air speed (AS). Probes whose parachutes open earlier (Chute) have a higher rate of failure than those whose parachutes open later (No Chute). At the lower air speed, the "Chute" failure rate is the same as the lowest rate in Figure 18, whereas the "No Chute" rate is the same as the highest failure rate in Figure 18.

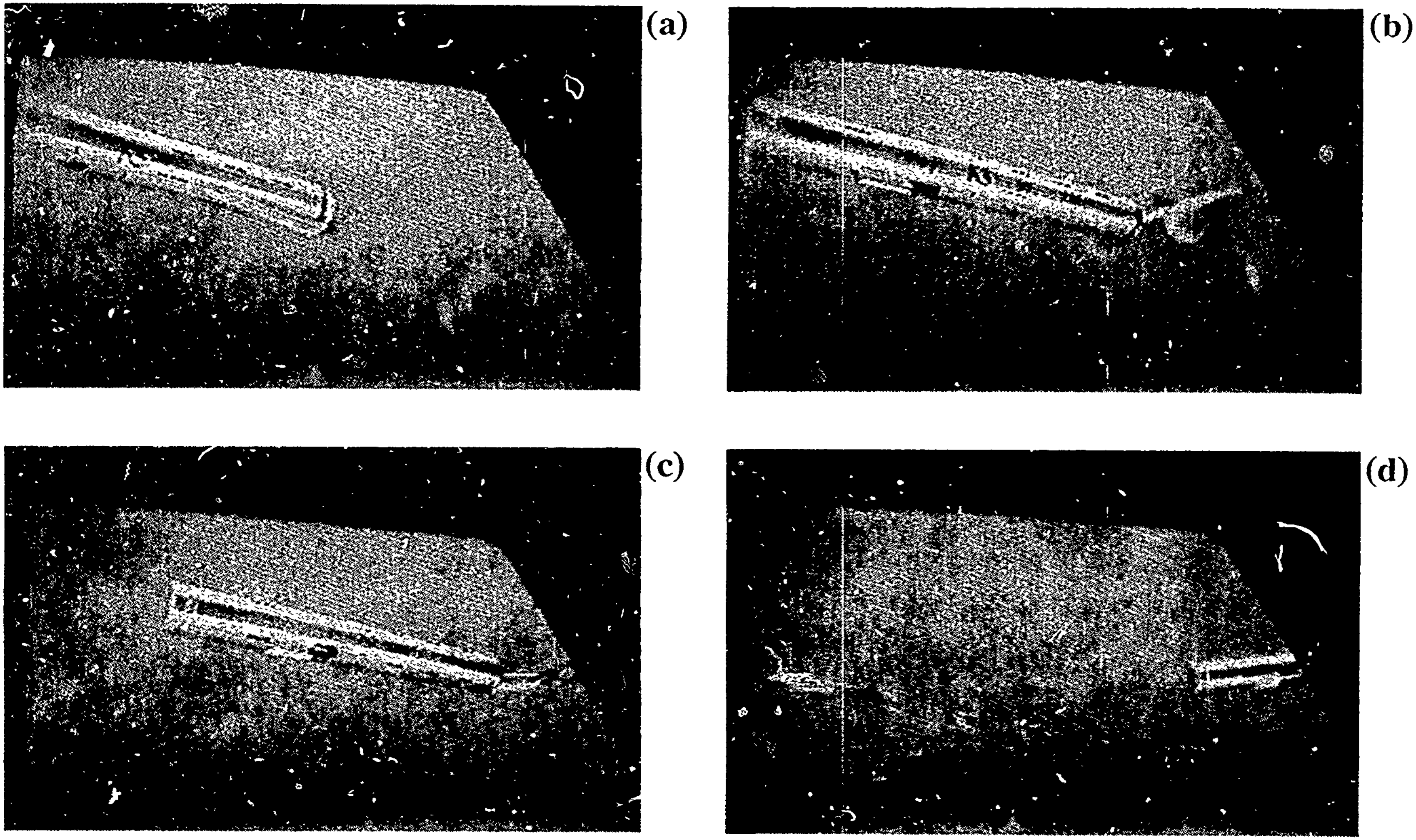
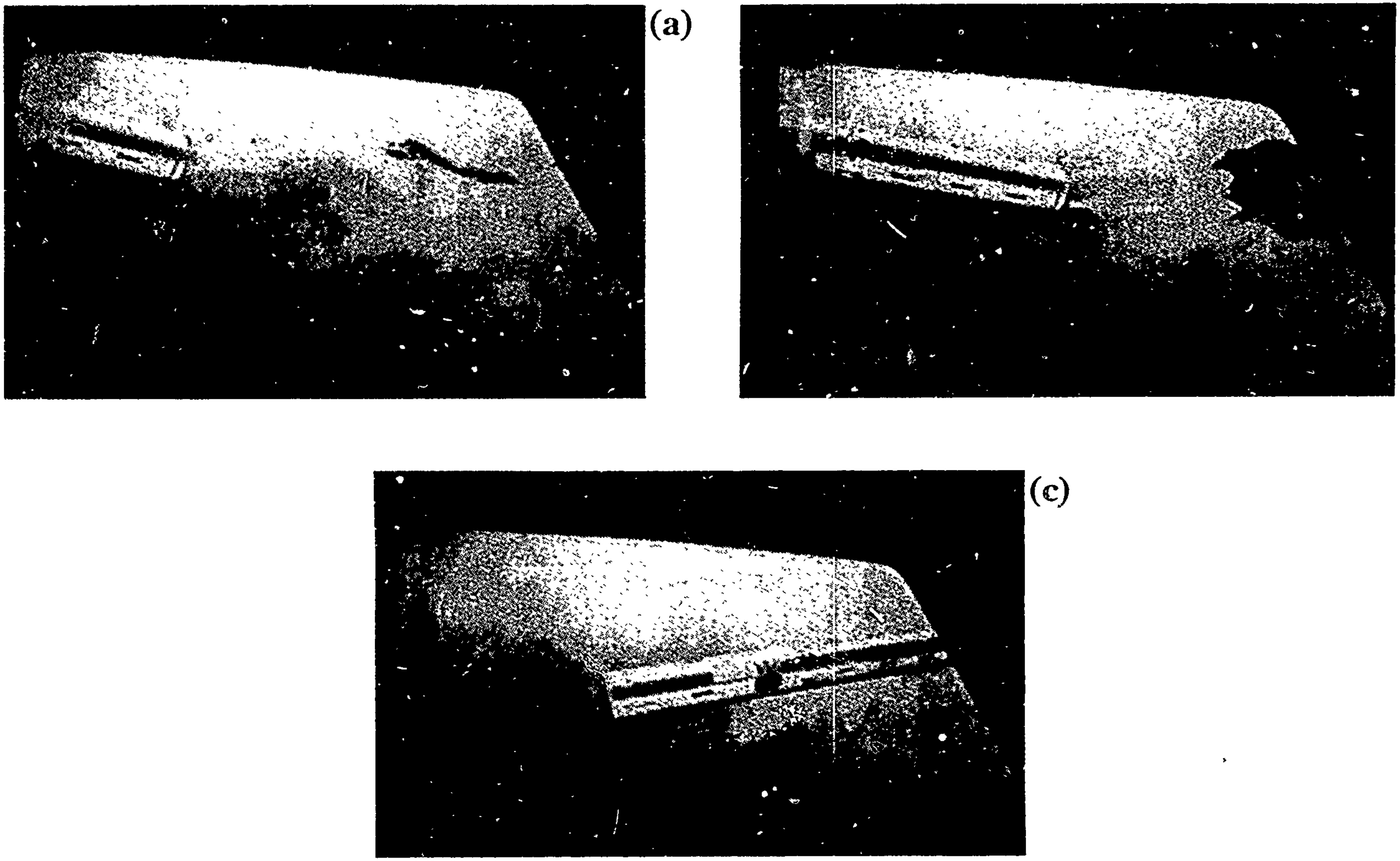


Figure 19. *AXCP deployment sequence viewed from downward-looking video camera. Effective shutter speed is 1/1000th second. Frames are 1/32nd second apart, but not all frames are shown here. Note wind flap separation and first stage of parachute deployment.*



(a) (b) (c)

Figure 20. As in Figure 19. Note parachute deployment.

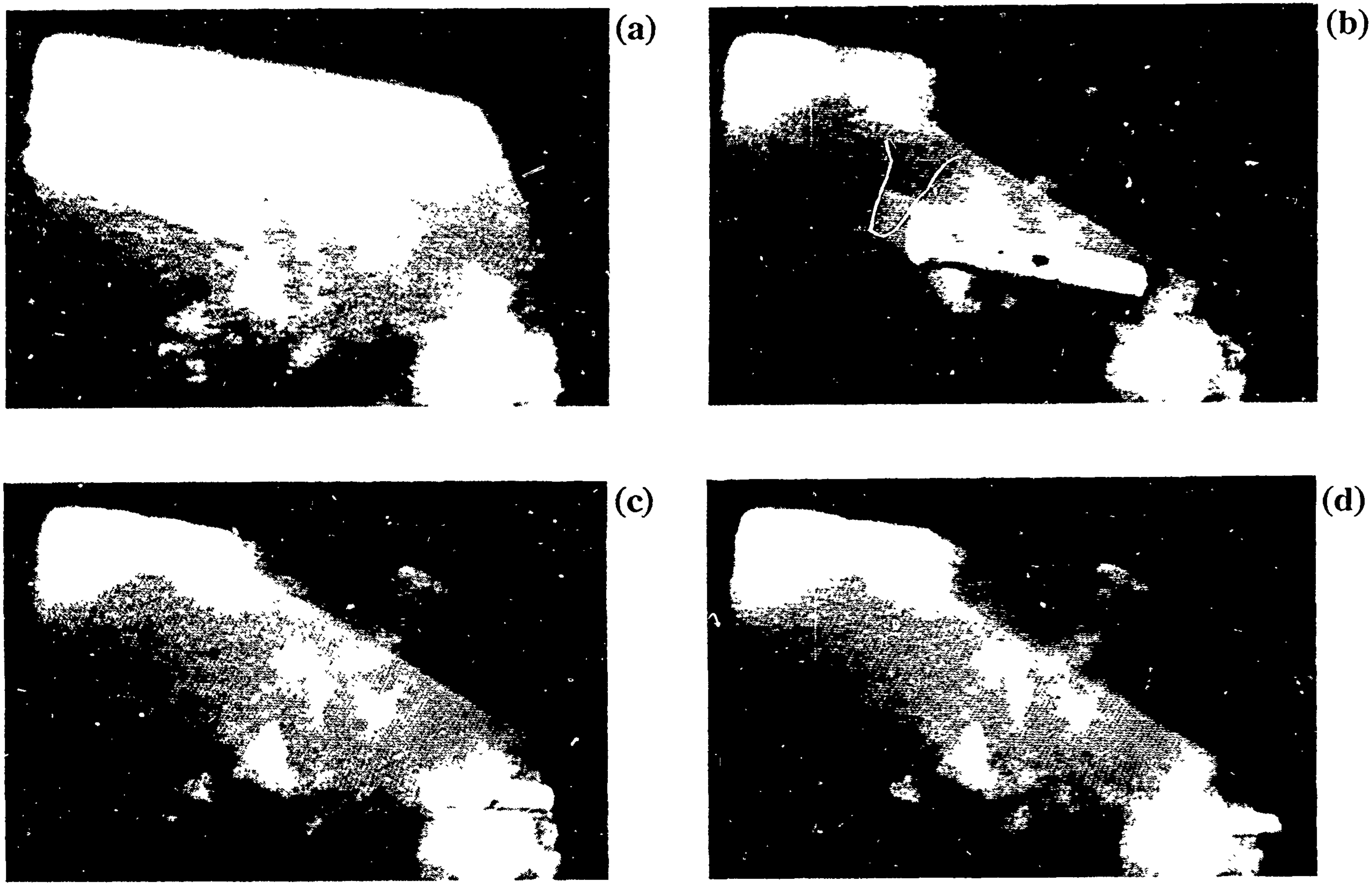


Figure 21. As in Figure 19. No parachute deployment is visible for this probe.

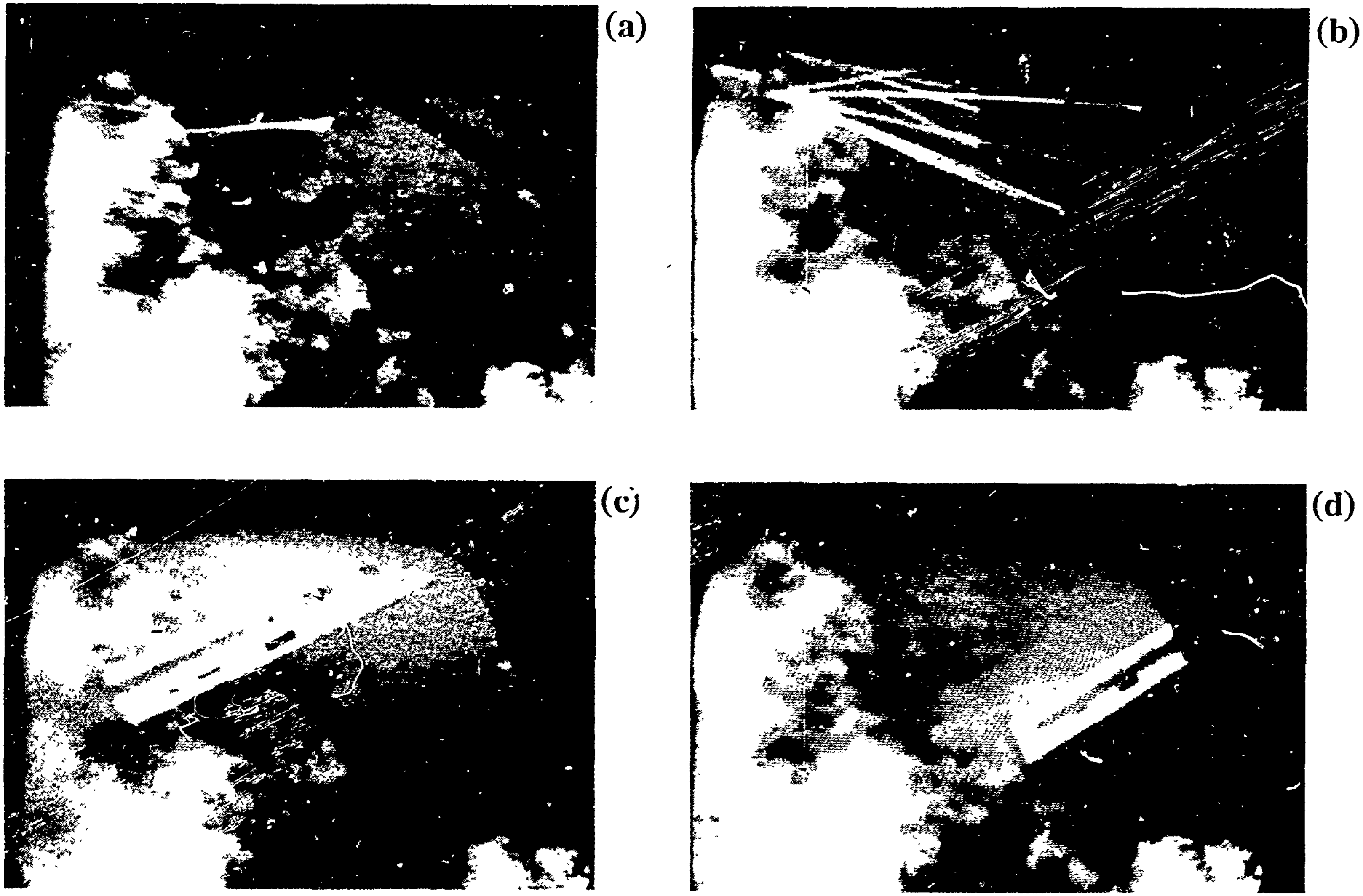


Figure 22. As in Figure 19. Note fully deployed parachute entering field of view from left and violent motion of AXCP.

Table VII. Analysis of AXCP deployment pictures.

	AS < 215 kn		AS > 215 kn		ALL	
	Chute	No Chute	Chute	No Chute	Chute	No Chute
RF failures	4	3	5	2	9	5
Probes	14	26	18	10	32	36
Failure rate	28%±9%	11%±6%	28%±10%	20%±12%	28%±8%	14%±6%

The percent of probes with early and late parachute deployment varies with air speed:

	AS < 215 knots	AS > 215 knots
Chute	14	18
Probes	40	28
Rate	35%±8%	64%±9%

The parachutes deploy earlier, on average, at higher air speeds.

These data show that early parachute deployment is associated with higher probe failure, and that this occurs more often at higher air speeds. This again suggests that acceleration upon launch, which is increased if the parachute opens early, is the cause of the AXCP failures.

Movies of sonobuoy and AXBT deployments from Navy P-3s do not show the great variability in probe behavior seen here. Furthermore, the parachutes deploy farther from the aircraft (Sippican, personal communication). The NOAA P-3, unlike Navy P-3's, has a 3.5-m diameter, 2-m thick radar dome located on its belly roughly 9 m in front of the launch tube. This can be expected to produce an energetic turbulent wake near the launch tube. It seems likely that the irregular behavior of the probes is due to the irregular, turbulent flow in the region of the launch tube. Evidence for a highly turbulent flow is found in the rapid acceleration of the probes even when the parachute is not deployed. Figures 23a and 23b trace the positions of two AXCPs in sequential frames 1/32nd second apart. The probe in Figure 23a (2303) falls away from the plane while retaining its orientation, whereas the one in Figure 23b (2305) yaws nearly 90°. This motion could easily be due to a turbulent eddy shed by the radar dome.

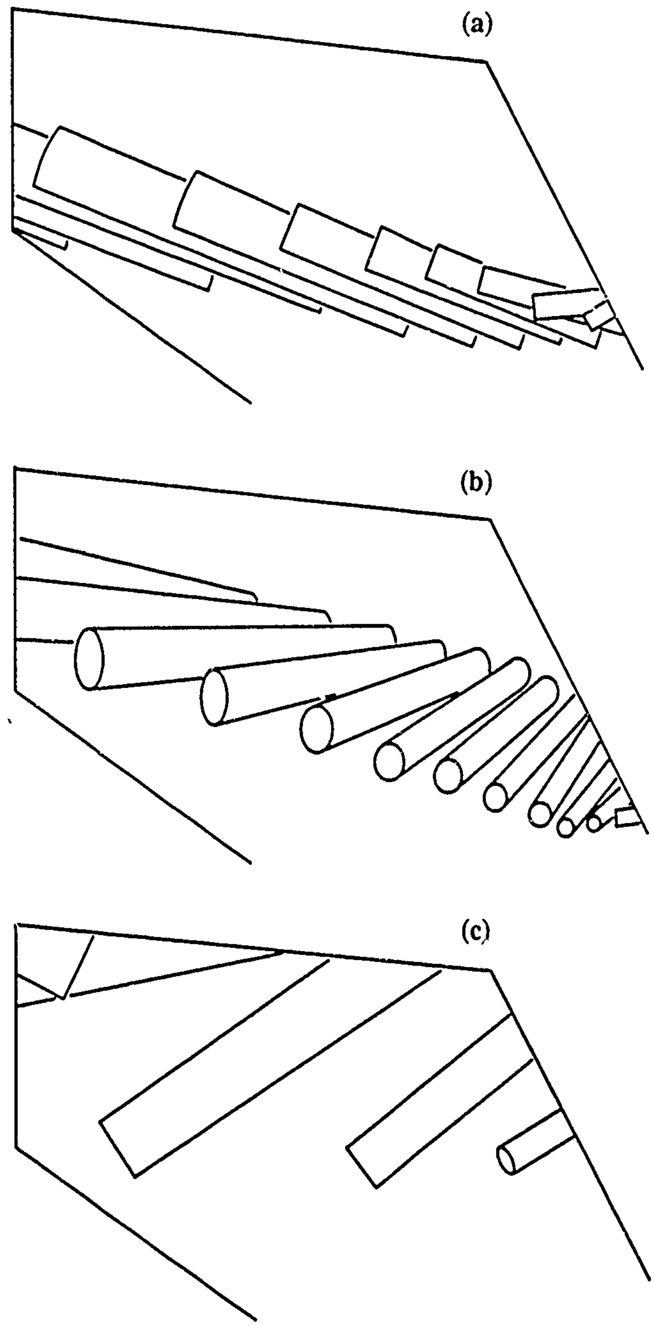


Figure 23. *Sketches of AXCP positions in sequential frames. (a) 2303, 1 December 1987: Probe falls unperturbed until last three frames, when rotation indicates that the parachute opens. (b) 2305, 1 December: Probe yaws strongly until last few frames, when rotation indicates that parachute opens. (c) 2301, 2 December: Probe rotates 90° in first three frames because of immediate parachute deployment.*

5.2.4 *Force and Acceleration Analysis*

Several sequences of images were analyzed to determine the accelerations and forces acting on the AXCPs during launch and parachute deployment. The physical parameters used in the computation are shown in Table VIII. Note that the center of mass of the AXCP is located approximately at the large holes in the side of the can, through which the electrode tape is removed. These were easily seen in the images.

Table VIII. AXCP physical parameters.

Parameter	Symbol	Value
Mass	m	8.4 kg
Length	l	0.87 m
Center of mass		
From chute end	l_1	0.52 m
From other end	l_2	0.35 m
Moment of inertia	I	1.5 kg m^2
Radius	r	0.061 m

The AXCP falls at an equilibrium speed V_e of about 25 m s^{-1}. To calibrate the drag coefficient and parachute area of the probe, we use the standard drag law formulation

$$gm = \rho_{\text{air}} C_D A_p V^2 \tag{1}$$

and $V = V_e$, yielding $C_D \rho_{\text{air}} A_p = 0.13$.

The force exerted by the parachute in the images was computed by estimating the acceleration of the center of mass of the AXCP. Lens distortion was corrected by making all measurements in units of the local AXCP diameter. Figure 24 plots the velocity of a probe (N16, 12/2/88). The AXCP accelerates at about 3 g after the parachute deploys, corresponding to a force of 246 N. From (1), this implies $V = 43$ m s^{-1}, so the air speed relative to the aircraft is about 50 m s^{-1}. This is only half the true air speed, providing further evidence that the probe is in the wake of the P-3's radar dome.

Far greater forces are found when the angular motion of the AXCP is considered. Angular displacements of 1 radian or more occur in one or two frames when the parachute opens (Figures 22, 23b, and 23c). This corresponds to an angular velocity ω of

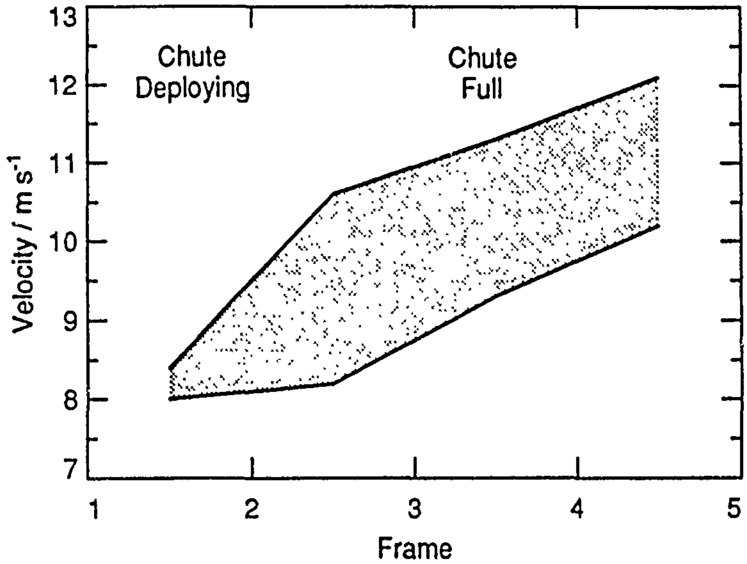


Figure 24. Velocity of AXCP 2320 (2 December 1987) relative to P-3 in camera plane, computed from video images. Shaded region indicates range of velocities, computed using different compensations for varying range and lens distortion. Frames are 1/32nd second apart.

15 rad s^{-1} and an associated centrifugal acceleration about the center of mass at the parachute end of the AXCP of $\omega^2 l_1 = 130$ m s^2, or 12 g. The angular acceleration $\omega_t \approx 450$ rad s^{-2}. This corresponds to an acceleration of the parachute end of the probe of $l_1 \omega_t = 234$ m s^{-2}, or 24 g. Assuming that this is due to a force, F, applied at distance $0.5\, l$ from the center of mass,

$$\frac{Fl}{2} = I\,\omega_t\,, \tag{2}$$

yielding $F = 2600\,N$, or 265 kg-force. If applied to the body as a whole, this would result in an acceleration of 31 g. These forces are clearly an order of magnitude larger than the parachute drag. They are probably due to lift on the AXCP body and/or buffeting by the turbulence near the launch tube. Whatever their origin, the forces result in accelerations of 25 g or greater in a direction perpendicular to the axis of the AXCP at the parachute end of the probe. We suggest that it is these accelerations that caused the observed probe failure.

Osse et al. (1988) measured accelerations on AXCPs dropped from a small plane with an air speed much less than 180 knots. The maximum accelerations were at least

100–150 g, far larger than calculated here. Nevertheless, the failure rate of the probes was very low. Most likely, these large accelerations occurred when the AXCP's hit the water, and thus were axial, rather than radial as found here. We therefore conclude that the AXCP is capable of taking rather large axial accelerations without failure but is sensitive to radial accelerations of 25 g or more.

5.2.5 *Conclusions of Failure Analysis*

The AXCP failures in OCEAN STORMS were correlated with air speeds in excess of 210 knots true and with early deployment of the parachute after launch. This indicates that the failures occurred at launch and were probably caused by high accelerations associated with early parachute deployment.

The radar dome on the underbelly of the NOAA P-3 probably produces a highly turbulent flow in the vicinity of the launch tube which may cause the parachute to deploy prematurely.

AXCP failures were much greater when the probes were launched "improperly." The correct way is

(a) with the wind flap down (i.e., the probe should go into the launch tube flap first)

(b) with the wind flap facing the wind (i.e., the wind flap should face the front of the aircraft as the probe falls down the tube).

We found an increase in RF failures to 30% at air speeds below 210 knots if (a) was followed but (b) was ignored.

There was no correlation between surface wind speed and AXCP failures. Some of the highest success rates occurred at surface wind speeds in excess of 60 knots.

AXCPs launched in the proper way from the NOAA P-3 at true air speeds less than 210 knots at 5000 ft had a failure rate of 11% due to RF failures and 8% due to other failures, for a total failure rate of 19%.

Dynamical analysis of AXCP motion shows that the AXCPs experienced accelerations of at least 10 g along their length, and at least 25 g sideways, upon exiting the NOAA P-3.

6. RECOMMENDATIONS

We suggest that a number of AXCPs be launched from the NOAA P-3 at true air speeds in excess of 230 knots and then be recovered. These should show a high failure rate and can be examined to determine the cause.

We suggest that AXCPs be subjected to accelerations in excess of 30 g in various directions perpendicular to their major axis in a controlled manner, followed by accelerations in excess of 150 g along their major axis. Analysis may reveal the cause of the failures we experienced during OCEAN STORMS.

7. REFERENCES

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APPENDIX A
AXCP Testing

Equipment

The following equipment is needed for AXCP checkout:

A 12 V power source — The +12 V side should be connected to a test lead; the ground side should be connected to a medical hemostat or other long clamping probe capable of reaching inside the AXCP case. This is used for powering the RF transmitter on the AXCP.

A −12V, 0, +12 V power source — This should be connected to a three-pronged test rig such as that shown in Figure A1. This is used for powering the AXCP probe.

A radio receiver capable of receiving the XCP transmit frequency. A Mk 10 and a headphone will work fine for this. We used a tunable radio manufactured by Yaesu (Model FRG-9600).

A small magnet for testing the magnetic field response of the XCP probe.

(optional) A spectrum analyzer for analyzing the output of the XCP probe.

The test points on the probe are illustrated in Figure A1. The testing procedure is explained in the following checkout log.

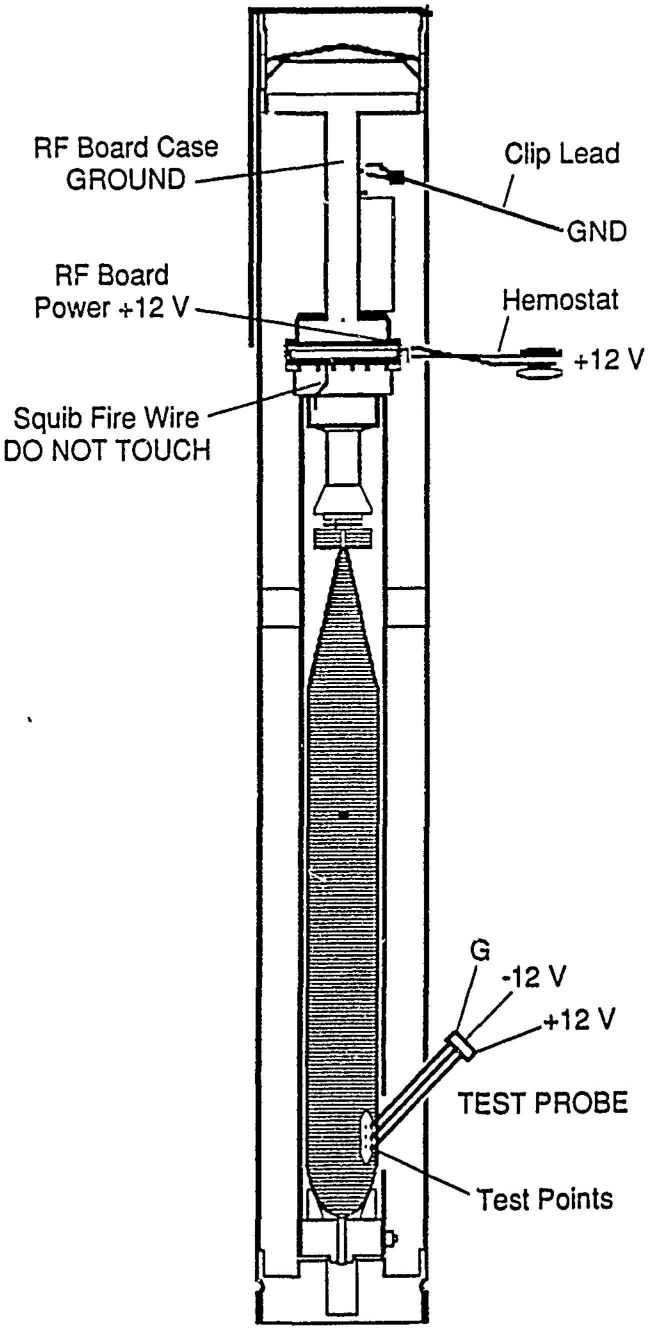

Figure A1. AXCP test points. Upper test points power RF link. Lower points power AXCP.

AXCP CHECKOUT

DROP # __________ PROBE # __________

MOD ________ CHANNEL _________

Initials __________ Date __________ Time __________

DO NOT remove the tapes until just before launching the AXCP.

RF TEST: Set up the test instruments as explained in the OCEAN STORMS documentation package. Be careful when attaching power to the AXCPs. Connecting power to the wrong wire will cause an explosion. There are two wires without insulation on them; both can be seen through the holes that are in the second row from the top of the launch canister. One wire is much longer than the other. The long one is the squib wire and should NOT have power applied to it. Check that the squib wire is not touching the AXCP case or the parachute canister.

SQUIB WIRE FREE _____________

The other wire is about 2 cm long. Using the 12 V power supply, connect the test clip (+12 V) to the short wire. In the hole on the canister directly above the short wire, a flat shelf can be seen; attach the ground wire (the hemostat) to this shelf. Turn on the power supply. You should hear quieting.

QUIETING _____________________

AF TEST: Connect the three-pronged AXCP test cable to the power supply. Be careful with the test probe; it carries 24 V of power. Apply power to the test points on the AXCP. Listen for the AXCP tones. You should see the three peaks on the spectrum analyzer for temperature (0.35 kHz), electric field (1.20 kHz), and compass coil (2.40 kHz).

AXCP TONES ___________________

Peaks: Temp __________ EF __________ CC __________

CC TEST: Wave a magnet over the AXCP electrodes. You should hear a warble.

CC WIGGLE ____________________

Comments:

AXCP LAUNCH LOG

use one for each probe

DROP # __________ PROBE # __________ CHANNEL __________

Initials __________ Date __________ Time __________

Remove the two pieces of tape that are inside the metal canister, and cover the AXCP's electrodes. Attach the tape to this sheet. Make sure that the plastic slide came off with the tape.

Remove the piece of fiberglass strapping tape from the outside of the metal canister and attach to this sheet. Do not pull on the plastic lever.

Tape and Slide 1	Tape and Slide 2	Fiberglass Tape

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19 ABSTRACT (Continue on reverse if necessary and identify by block number)

In the fall of 1987, 199 Air Expendable Current Profilers (AXCPs) were deployed from a NOAA P-3 aircraft as part of OCEAN STORMS, a study of air-sea interaction under strong storms in the northeast Pacific Ocean. The procedures used to prepare and launch the AXCPs are described, and the instrumentation and methods used to record, process, and display the received data in real time are detailed. The chronology of OCEAN STORMS and the AXCP drops is given, and a few examples of the profiles are provided. The modes of AXCP failure are reported, and recommendations for improving performance are made.

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